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THE NUCLEAR HANDBOOK FOR INSTRUCTORS AND STAFF OFFICERS

Promulgated by
Command of the Army Council

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Promulgated by
Command of the Air Council

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134. The split of the uranium nucleons into two fragments is uneven. Averaged over a large number of slow fissions of uranium[235] (and practical cases always involve large numbers of nuclei) a range of pairs of fragments results. About 97 per cent of the fissions yield a "light" fragment of mass number between 85 and 104 and a complimentary "heavy" fragment of mass number between 130 and 149. Fig 14 illustrates this distribution.

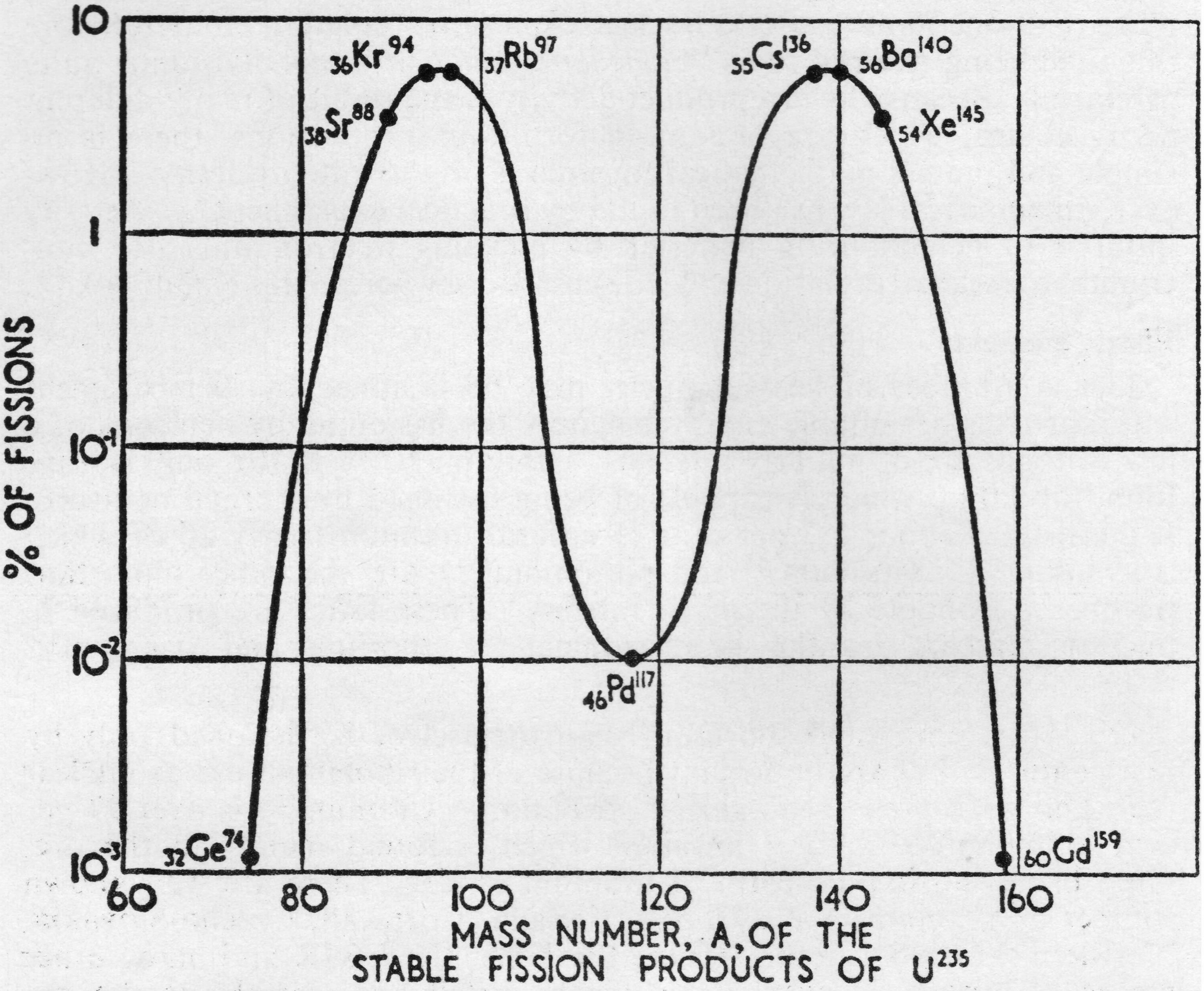

Fig 14.—The yield of stable fission products as a function of mass number. The fission products total 200 per cent of the number of fissions. Although the curve is continuous only points corresponding to the whole mass numbers represent actual fissions

135. The fission of plutonium[239] by fast neutrons as may occur in nuclear explosions gives a slightly different, though essentially similar, distribution of fragments.

136. The fragment nuclei still have too many neutrons for stability and decay in fission decay chains by successive beta emission accompanied by gamma radiation. An example is:—

$$\underset{\text{Xenon}}{{}_{54}Xe^{140}} \xrightarrow{\text{16 seconds}} \underset{\text{Caesium}}{{}_{56}Cs^{140}} \xrightarrow{\text{Short}} \underset{\text{Barium}}{{}_{56}Ba^{140}} \xrightarrow{\text{12·8 days}} \underset{\text{Lanthanum}}{{}_{57}La^{140}} \xrightarrow{\text{40 hours}} \underset{\text{Cerium}}{{}_{58}Ce^{140}} \text{ (stable)}$$

* About 10^9 centimetres per second.

The elements produced in decay chains are collectively termed *fission products*. There are more than eighty possible fission fragments and more than sixty different decay chains, each, on the average, of three stages. Fission products are thus very complex mixtures of various isotopes of all the elements from zinc $\left({}^{72}_{30}\mathrm{Zn}\right)$ to gadolinium $\left({}^{159}_{64}\mathrm{Gd}\right)$ and the composition changes as time passes.

Residual radiation

137. The radiation from the fission products forms part of the ***residual*** *radiation*. (In military parlance this term refers to that radiation emitted more than one minute after a nuclear explosion; radiation emitted before this time being referred to as "*immediate radiation*": this division is quite arbitary.) Because fission product activity is the result of many different decay chains, which are present in fortuitous proportions, there is no simple and precise mathematical formula giving its rate of decay. However, an empirical law has been found by practical experiment*. Activity induced in neighbouring material by escaping neutron flux also contributes to residual radiation and is discussed elsewhere in this Handbook**.

Fissile elements

138. A number of heavier nuclei may be fissioned by bombardment with particles of suitable energy but only the fissioning by neutrons of a few isotopes are of military interest. Uranium^{235}*** is the only isotope found in nature which is capable of being fissioned by thermal neutrons. It constitutes about 0·7 per cent of natural uranium nearly all of which is uranium^{238}. Uranium^{233} and plutonium^{239}† are the other important isotopes fissionable by thermal neutrons. These latter are produced in nuclear reactors by the bombardment of thorium and uranium^{238} respectively††.

139. Uranium^{238} and thorium^{232} can themselves be fissioned only by fast neutrons, but are important because of their potential use as nuclear fuels and widespread geological distribution. Uranium^{238} is over 99 per cent abundant in natural uranium which is found mainly in the ore, pitch blend, an impure form of uranium oxide. There are well known sources of uranium in the Congo, Canada, Cornwall, Czecho-Slovakia, Northern Australia, South Africa, the USA, the USSR and many other places. Thorium is even more widely distributed, mostly as the ore thorite, but also as monazite which, although it contains only 15 per cent of thorium as against the 50 per cent of thorite, has been the principle source up to the present. Monazite is worked in Brazil and Southern India while thorites are found in Australia, Brazil, Madagascar, Scandinavia, the UK, USA and USSR.

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* The mathematical formula is:—$It = It^{-1 \cdot 2}$
where It = radio-activity (dose rate) at a time t
I = radio-activity at unit time, eg, H+1 hour or day
t = elapsed time from burst in the same units of time, eg, hours or days
The formula is used in constructing the scales of the Radiac Calculator, *see* Chapter 6.

**The rates of decay of neutron induced activities depend very much on the particular materials irradiated. The $t^{-1 \cdot 2}$ law will be departed from in most practical cases.

***Uranium^{235} is an alpha emitter with a half-life of $7 \cdot 1 \times 10^{8}$ years. It also spontaneously disintegrates by fission but the rate is very slow, about 40 fissions per minute per gram. Its specific gravity is about 18·9 (if water = 1; lead = 11·35), so that one cubic inch of uranium weighs about 0·68 lb.

† Plutonium^{239} is an alpha emitter decaying to uranium^{235} with a half-life of 24,000 years. The degree of alpha activity is enough to make it dangerous to handle. Since plutonium^{239} decays to uranium^{235}, which is also fissile, there is no economic loss in storage. Its density is also similar to that of uranium.

†† The reactions are:—

$$^{232}\mathrm{Th}\ (n, \gamma)\ ^{233}\mathrm{Th};\ ^{233}\mathrm{Th} \xrightarrow{\text{23 min.}} {}^{233}\mathrm{Pa} + \beta;\ ^{233}\mathrm{Pa} \xrightarrow{\text{27 days}} {}^{233}\mathrm{U} + \beta.$$

$$^{238}\mathrm{U}\ (n, \gamma)^{239}\mathrm{U};\ ^{239}\mathrm{U} \xrightarrow{\text{23 min.}} {}^{239}\mathrm{Np} + \beta;\ ^{239}\mathrm{Np} \xrightarrow{\text{2·3 days}} {}^{239}\mathrm{Pu} + \beta.$$

TABLE VI.—Types of nuclear explosion and their characteristics

Type of burst	Flash	Heat	Immediate effects: Blast and shock: Air	Immediate effects: Blast and shock: Ground or water	Immediate effects: Nuclear radiation	Residual: Radio-activity: Neutron induced	Residual: Radio-activity: Fall-out
High or medium air burst	Intense	Considerable	Considerable	None	Considerable	Negligible	None, but there may be rain out from weapons under 10 KT
Low air burst ..	Intense	Considerable, but more concentrated	More concentrated over smaller area. Scouring around GZ	None	Very considerable	Considerable in a circular pattern round GZ	None, but there may be rain out from weapons under 10 KT
Surface burst ..	Less, but still considerable	Less	More concentrated still over even smaller area. Some cratering	Some	Less, but still considerable	Considerable, but fission products predominate	Extensive over a large area.
Shallow under-surface burst	Less still	Less still	Less, but extensive cratering (*See* footnote)	Considerable	Considerably less	Considerable, but fission products predominate.	Very extensive. Dust cloud on land. Base surge in water.
Deep under-surface burst	None	None	None if burst does not vent, camouflet formed	Considerable	None	Concentrated around point of burst, ie, in the camouflet. Fission products predominate	

Note.—With the shallow underwater burst, the fall-back of vast quantities of water sets up a wave formation.

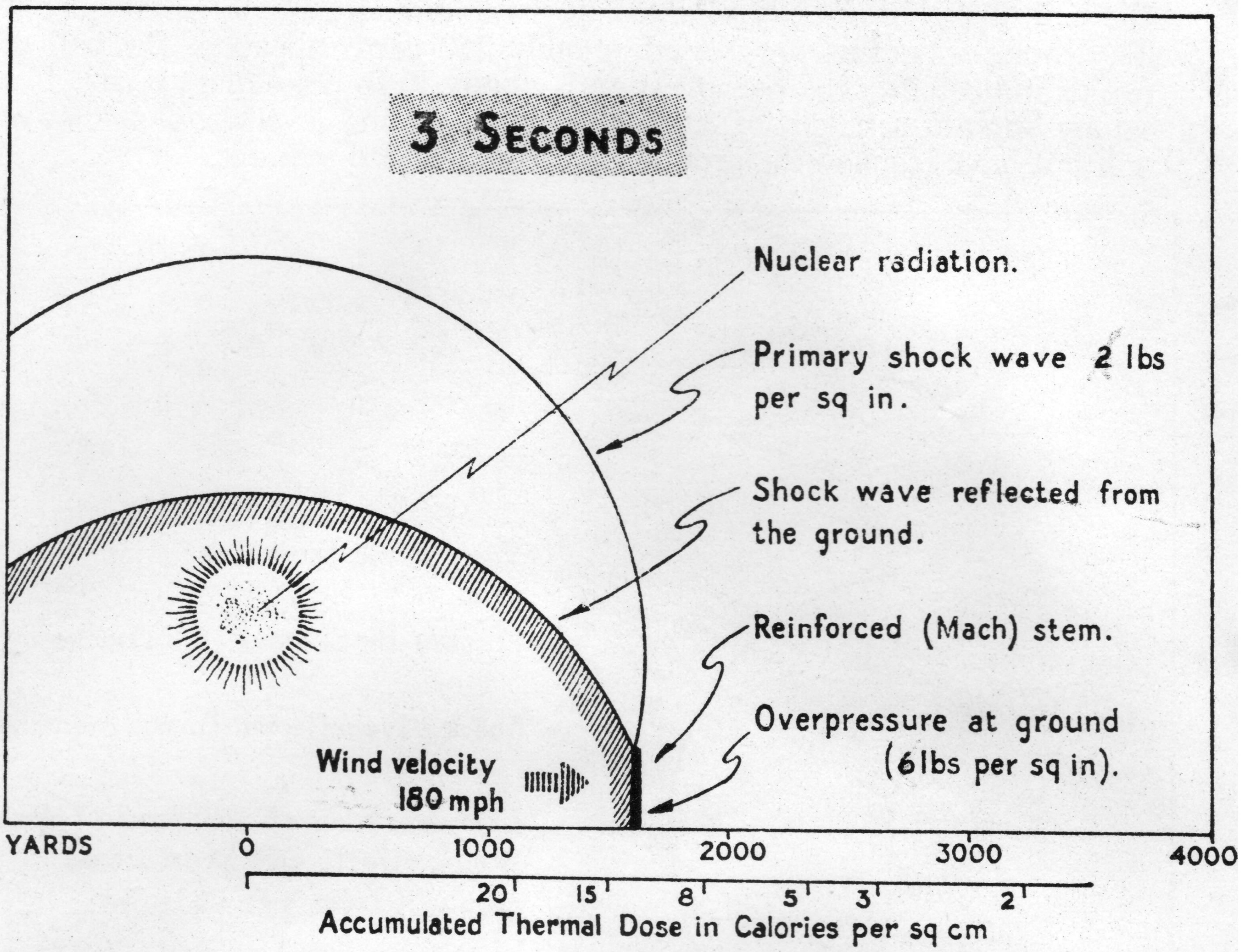


Fig 21(*c*).—Chronological development of a nominal nuclear air burst—3 seconds after detonation

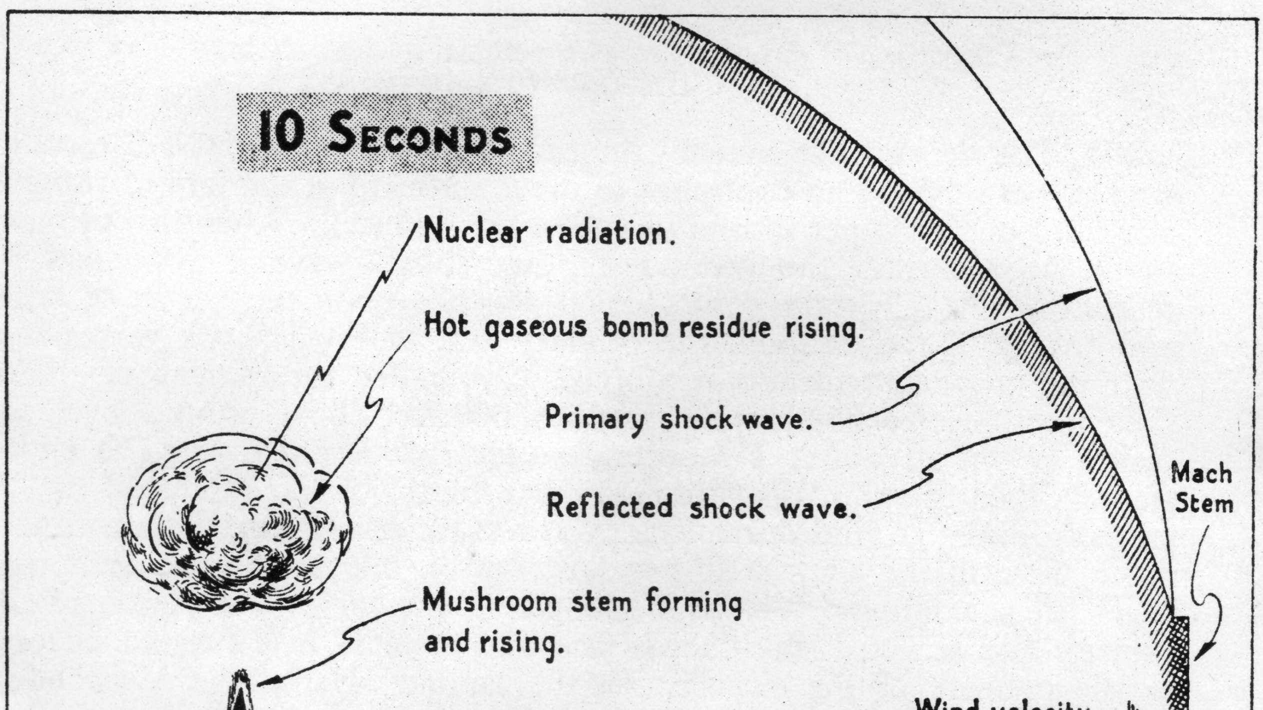


Fig 21(*d*).—Chronological development of a nominal nuclear air burst—10 seconds after detonation

TABLE IX.—Chart of windspeeds, duration of shock front, overpressures and damage to be expected from an air burst 20 kiloton weapon

Time of arrival of shock front (secs)	Wind velocity, mph	Duration (secs)	Overpressure, psi	Dynamic pressure psi	Miles	Yards	DAMAGE
						↑	Light damage—out to 8 miles
10·3	40	1·27	1·1	—			← Oil storage tanks, filled: slight damage.
						4,500	
					2½		
9·0	53	1·17	1·5	—		4,000	← Homes—Plaster damage, window breakage.
					2¼		
							← Flash charring of telegraph poles.
	60	1·11	1·7	—	2		
						3,500	← Structures—Limit of partial damage.
	70	1·06	2·0	0·09			← Blast damage to majority of buildings. Flash ignition of dry combustible material. WOODEN FRAME BUILDINGS—Light damage.
					1¾		
6·5	78	1·03	2·25	0·12		3,000	← Heavy plaster damage. Radio, TV transmitting towers and smoke stacks—slight damage.
	95	0·98	2·9	0·22	1½		← Structures—Limit of moderate damage. RADIO, RADAR, VEHICLES, REINFORCED CONCRETE and STEEL FRAME BUILDINGS—Light damage.
						2,500	
	112	0·94	3·5	0·31			← Multi storey brick buildings—structural damage. Roof tiles bubble.
					1¼		
							← Telephone and power lines. Limit of significant damage.
4·2	130	0·90	4·2	0·4		2,000	← ARTILLERY—Light damage. RADIO, RADAR, LIGHT STEEL FRAME Buildings—Moderate damage. 9 inch brick walls cracked.
							WOOD FRAME HOUSES—Destroyed.
	153	0·85	5·4	0·70	1		← STRUCTURES—Limit of severe damage. ELECTRIC INSTALLATIONS and TROLLEY CARS—Destroyed.
						1,500	← REINFORCED CONCRETE Structures—Moderate damage. BRIDGES—Moderate damage.
MACH REFLECTION ↑	234	0·78	7·6	1·2	¾		← RADIO, RADAR, LIGHT STEEL FRAME BUILDINGS—Severe damage. LIGHT VEHICLES and HEAVY STEEL FRAME BUILDINGS—Moderate damage.
							← LIGHT ARTILLERY, HEAVY VEHICLES—Moderate damage.
2·2	294	0·71	10	2·2		1,000	
					½		← Virtually complete destruction of all buildings other than reinforced concrete, aseismic design. OIL STORAGE TANKS, filled—Severe damage.
							← LIGHT VEHICLES—Severe damage.
0·8	384	0·64	14	3·5		500	← LIGHT ARTILLERY, Reinforced concrete buildings—Severe damage.
					¼		← HEAVY ARTILLERY, TANKS—Moderate damage. HEAVY VEHICLES—Severe damage.
	306	0·55	24	2·5			
							← HEAVY ARTILLERY—Severe damage.
							← TANKS—Severe damage.
					0		Ground Zero (20 KT air burst)

Aircraft in flight

270. Aircraft flying within 1,500 yards of the point of detonation at the time of the explosion will probably suffer severe damage. Some damage can be expected out to 3,000 yards. It should be noted that aircraft in flight will usually be above the altitude of the Mach effect (*see* Sec 5, para 198) so that the radius of the damage due to air blast should be significantly less than for an aircraft parked on the ground.

Parked aircraft

271. In addition to damage from direct air blast (para 267), parked aircraft may be damaged by being lifted entirely off the ground, by tipping on to a wing or by overturning. The tendency to weathercock (ie, face the blast) and the resultant violent whip may damage fuselage and tail structures. Flying debris may be a further cause of damage. Since parked aircraft often have openings uncovered, by which blast may enter the interior, damage to equipment and flight instruments is possible. Table X gives an approximation of the possible damage range for parked aircraft.

TABLE X.—**Range of damage to parked aircraft from blast (20 KT weapon burst at 2,000 feet)**

DAMAGE		
Severe	Moderate	Light
0–1,800 yards	1,800–2,800 yards	2,800–4,000 yards
Smashed canopies and control surfaces.	Severe damage to light structural components.	Damage to light components.
Buckling and breaking of monocoque and semi-monocoque fuselages.	Dished cowling and missing cowl flaps.	
Split wing tanks.	Dished in and buckled fuselages and wing tanks.	
Significant damage to air foils.	Dished skins on wings but no damage to framing of heavier structural components.	

Tanks

272. Tanks and armoured cars are very resistant to blast and shock, particularly if closed down. When closed down the following exposed equipment is vulnerable—wireless aerials and mounts, sighting mechanisms, machine gun mounts, lights, road wheels, suspension etc. Tanks not properly closed down will suffer severe interior damage through the blast wave entering ports and hatches. Near the ground zero such damage may occur through the failure of motor ventilation openings and inspection plates even if the tank is closed down. The blast may throw the tank some distance or overturn it. Skirting plates, tool and kit boxes and other outside fixtures may be torn off and thrown considerable distances by the drag pressure. (*See* Tables IX and XI for damage range.)

Ordnance and ammunition

273. Artillery weapons, particularly the heavier natures, are very resistant to blast effects but delicate parts such as the sights and fire control

injured by flying debris and glass; buildings may collapse on them. In JAPAN 35 per cent of all casualties were indirectly attributed to blast, but none directly, except in cases of ruptured ear drums.

Summary of the effects of blast damage

279. The relationship between blast damage and distance from ground zero for various objects of military interest for a 20 KT weapon burst (*a*) 2,000 feet above the target (*b*) on the surface are given at Table XI.

TABLE XI.—**Relationship between blast damage and distance from GZ for various objects. 20 KT weapon air burst at 2,000 feet and surface burst**

Nature of target	Damage	Range from GZ in yards	
		Airburst at 2,000 feet	Surface burst
Steel heavy framed buildings and reinforced concrete	Severe Moderate Light	750 1,400 2,700	1,000* 1,100* 1,900
Light steel framed buildings	Severe Moderate Light	1,400 2,000 2,700	1,100* 1,400 1,900
Brick houses	Severe Moderate Light	1,800 2,800 3,400	1,250 1,950 2,250
Oil tanks	Destroyed	about 1,400	about 1,000
Petrol stocks in open	Severe Moderate Light	600 1,000 1,400	600 700 1,000
Ammunition in the open	Severe Moderate Light	400 600 1,200	500 600 850
Supplies in wooden cases	Severe Moderate Light	500 1,000 1,600	450 700 1,100
Light vehicles	Severe Moderate Light	800 1,400 2,700	700 950 1,400
Tanks	Severe Moderate Light	200 450 2,000	450* 500 1,400
Bridges (side on)	Destroyed Displaced	800 1,000	600 1,000
Bridges (end on)	Destroyed Displaced	150 200	450* 500*
Field artillery	Severe Moderate Light	250 600 2,000	500 550 700

* In these cases either earth shock or crater formation is the main contributory cause.

280–289. Reserved.

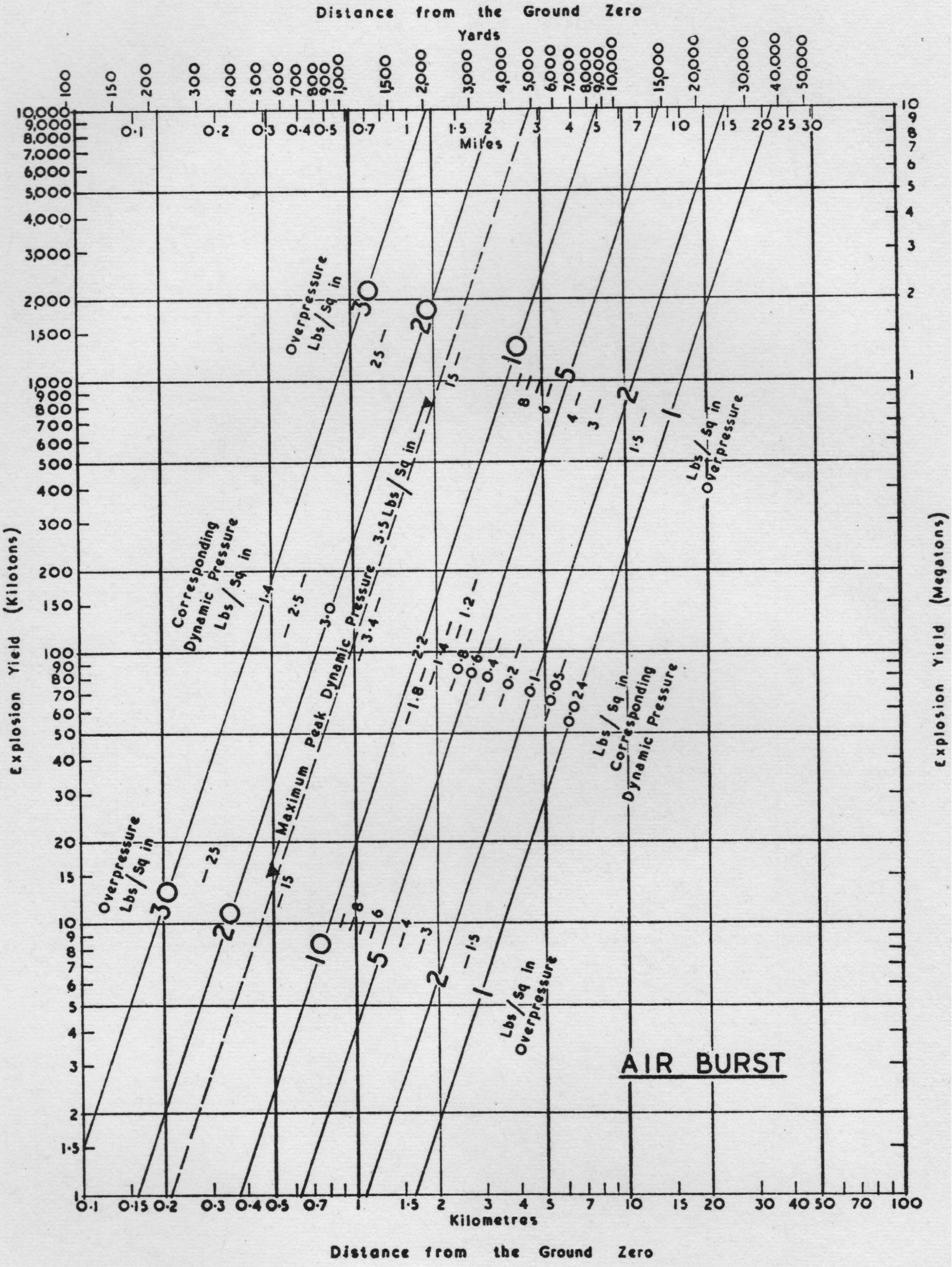


Fig 30(*a*) Peak overpressures on the surface for an air burst and corresponding horizontal component of the peak dynamic pressure

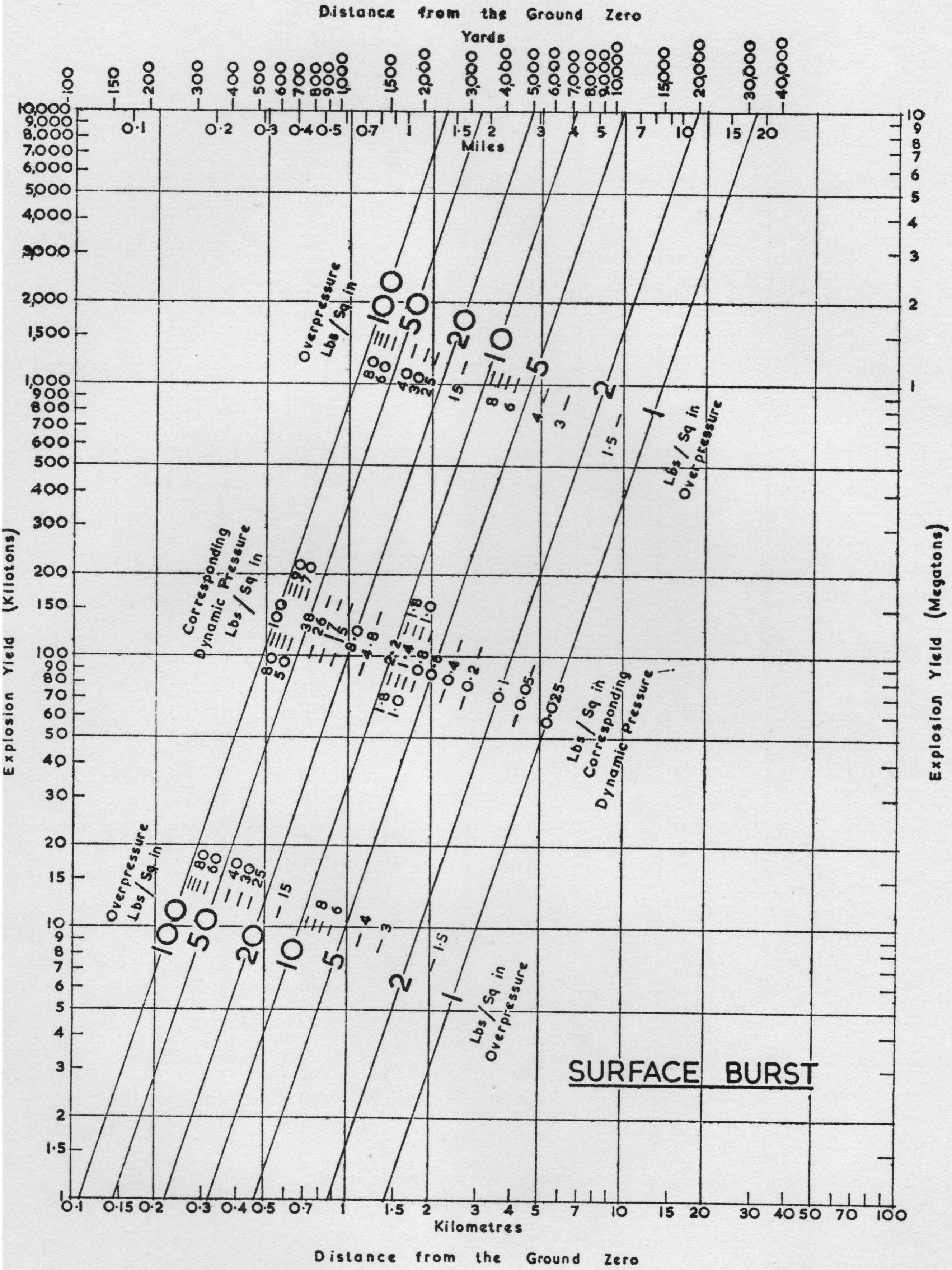


Fig 30(*b*).—Peak overpressures on the surface for a surface burst and corresponding horizontal component of the peak dynamic pressure

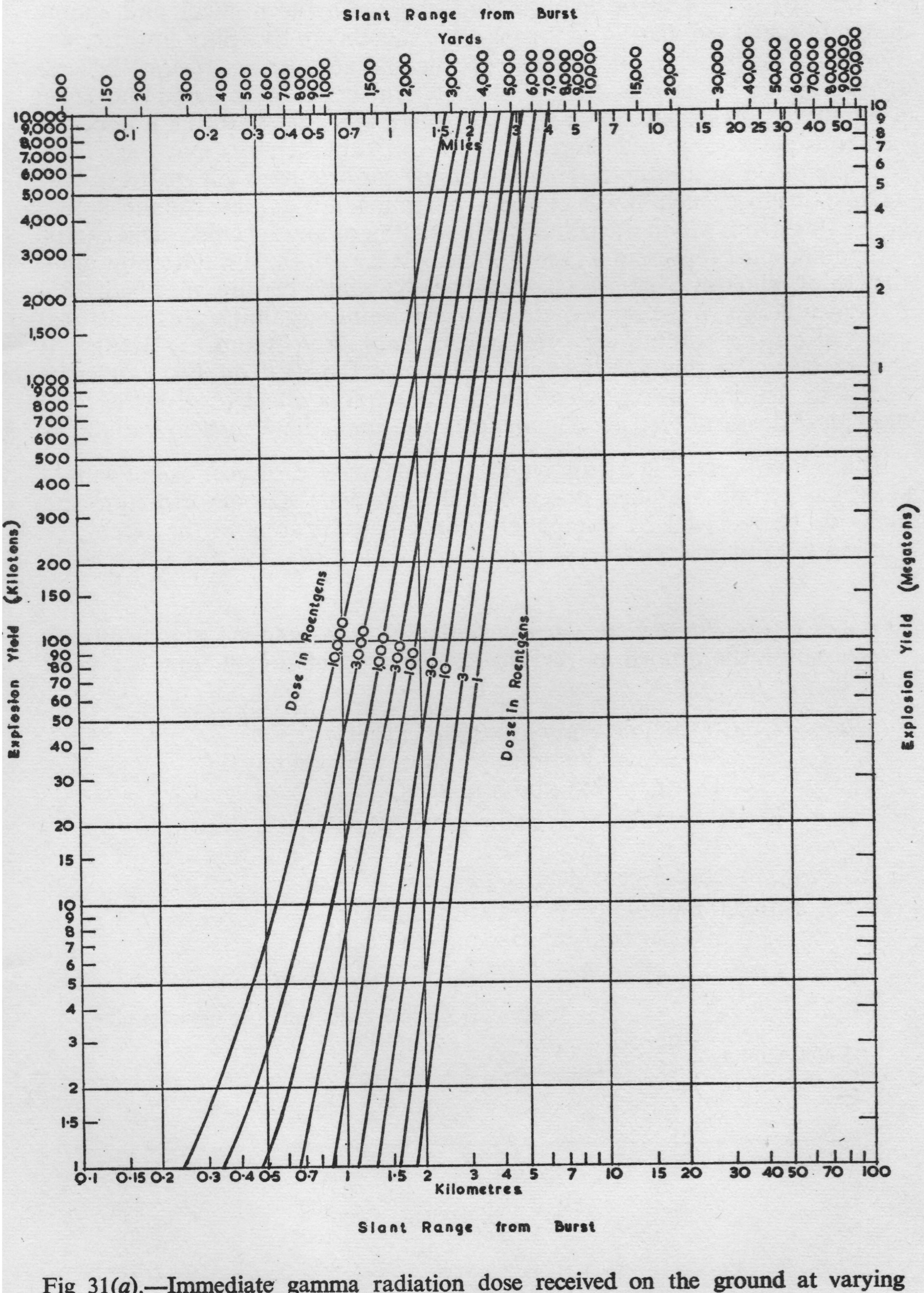


Fig 31(*a*).—Immediate gamma radiation dose received on the ground at varying distances (slant range) from an air burst

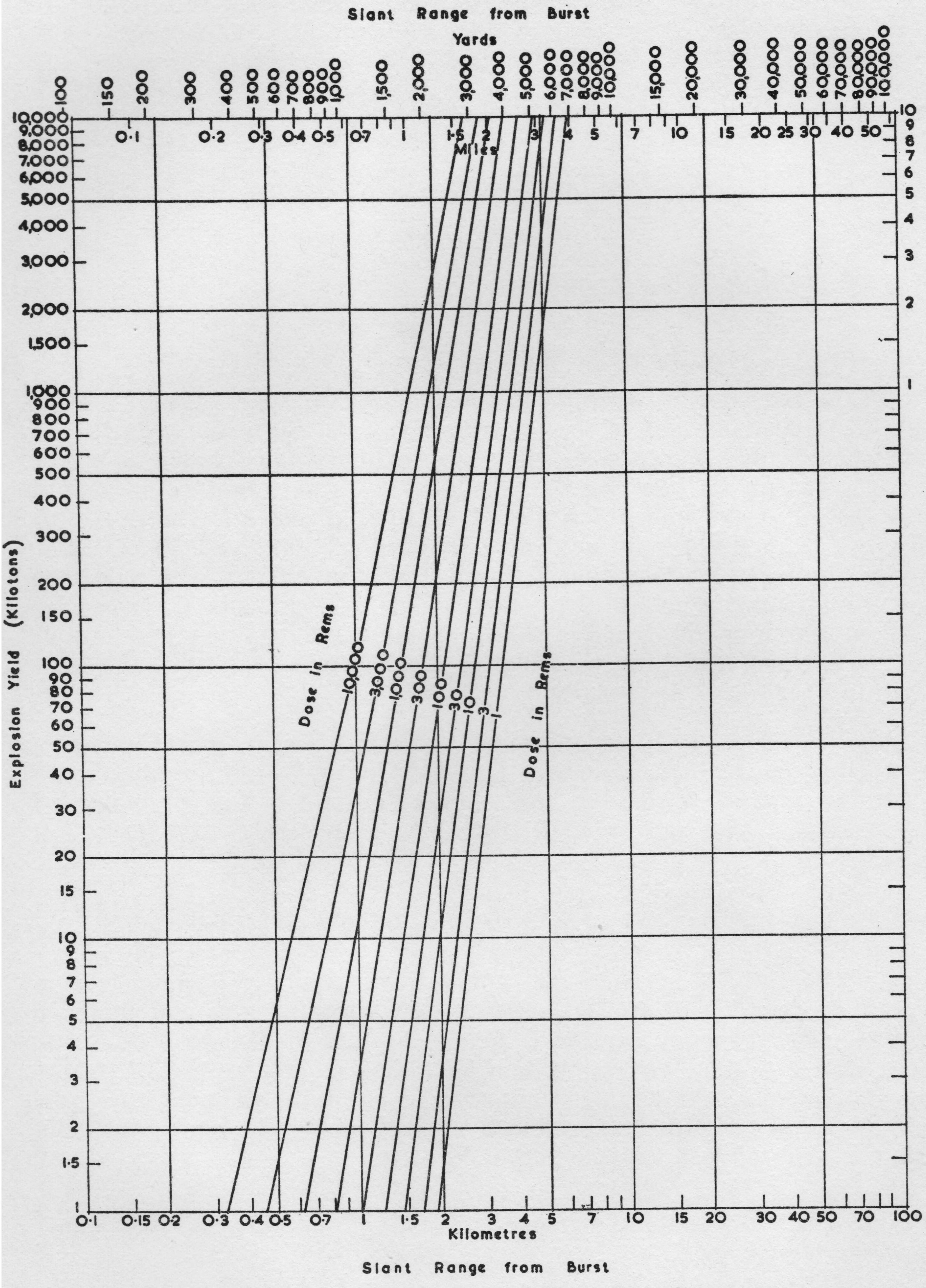


Fig 31(*b*).—Total dose of immediate nuclear radiation (neutron and immediate gamma radiation) received on the ground at varying distances (slant range) from an air burst.

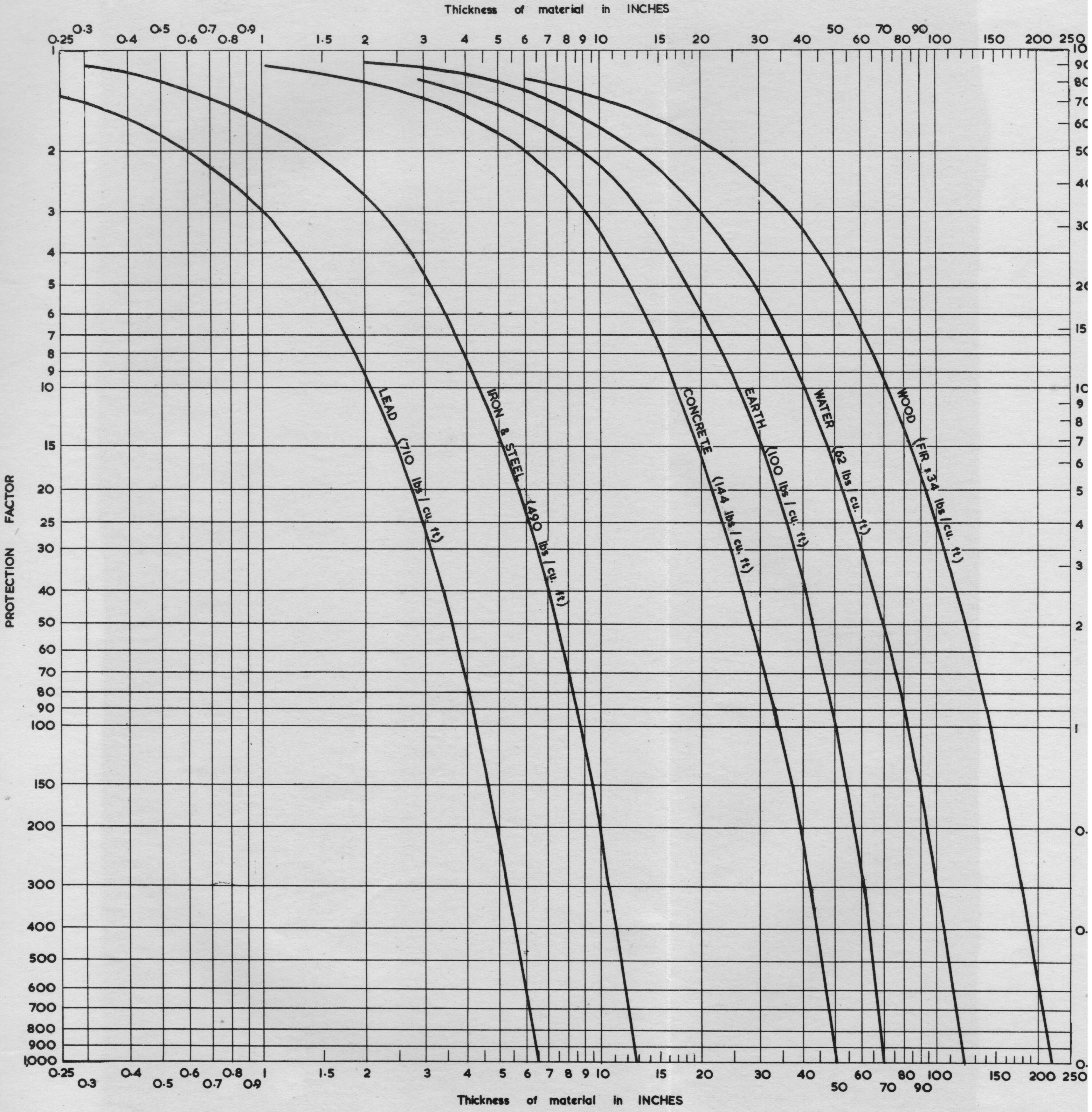
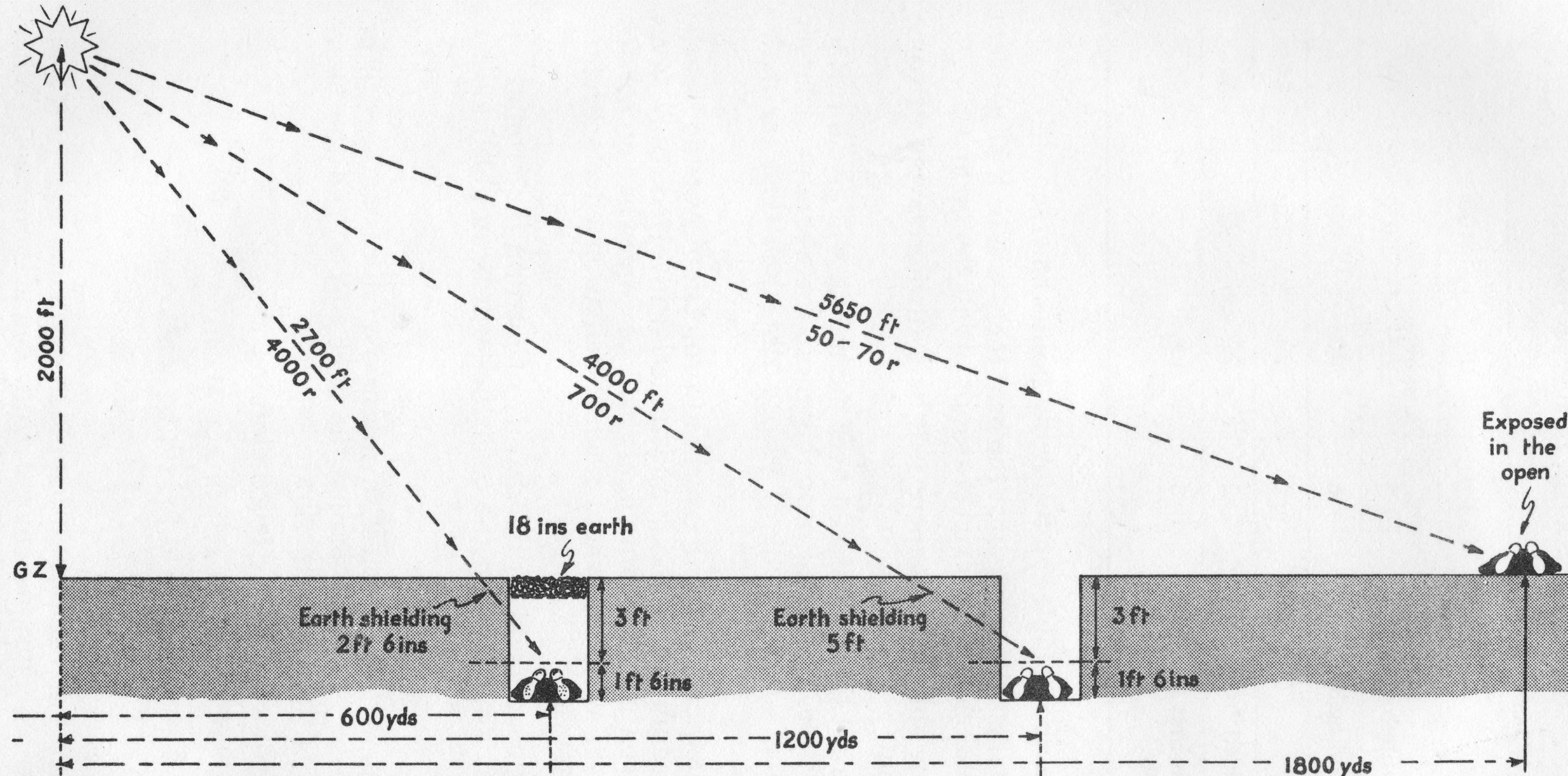


Fig. 33.—The attenuation of the IMMEDIATE gamma radiation (4·5 MeV)

to face 102

A*



		Without headcover	With headcover		
Total radiation		1000 r	300 to 400 r	about 175 r	50 to 70 r
Nausea & vomiting	1st day	100%	100%	25%	No decrease in fighting efficiency
Incapacitated	1st day	100%	probably 100%	65%	
Mortality	1st day	50%	unlikely	unlikely to be any	
Mortality at 6 months		75%	50%	upto about 5%	
Recovery period			3 months	3 weeks	

Fig 37.—Diagrammatic representation of the effects of nuclear radiation at 600, 1,200 and 1,800 yards from the ground zero of an air burst 20 KT missile

TABLE XX(*b*).—Estimated immediate casualties from a medium air burst 10 KT missile

Form of protection of personnel	Expected casualties Density of men per 1000 metre map square			Casualty saving per cent
	1	10	100	
1. In open, completely unprotected	20·5	205	2,050	0
2. In open, shielded from heat ..	4·6	46	460	77
3. In open slit trenches	3·2	32	320	84
4. In slit trenches shielded from heat	2·2	22	220	89
5. In trenches with 18 inches of earth overhead protection	0·8	8	80	96

From a study of the above table the following points emerge:—

(*a*) If troops can be shielded against the heat there will be a 77 per cent saving of total casualties, even if troops are in the open.

(*b*) By occupying slit trenches there will be a further saving of some seven per cent.

(*c*) A shield against the heat placed over the trench will give a further saving of five per cent (and probably more for weapons of larger yield), making a total saving of 12 per cent more than thermally protected troops in the open.

(*d*) Placing of 18 inches of earth overhead protection over the trench, with all the additional labour and material involved, only saves a further seven per cent (this figure will be somewhat higher for very low yield weapons where nuclear radiation effects become more important).

(*e*) Total casualties depend on the density of men on the ground. If the density is doubled then the casualties will be doubled also.

384. It is apparent that the greatest saving in overall casualties will be achieved if men can be protected against the heat effects. Of the many possible ways of doing this the simplest are:—

(*a*) The wearing of properly designed clothing.

(*b*) Immediate action drills for self-preservation.

(*c*) Provision of a thermal shield for slit trenches.

385. While the figures in Table XX(*b*) apply in particular to a 10 KT air burst missile, similar conclusions emerge from calculations with other yields and other burst heights. For example, at Table XX(*c*) is an estimate of the saving in casualties for differing yields of weapon by shielding men in the open from the heat effects.

TABLE XX(*c*).—**Saving in casualties by shielding from the heat effects for varying yields of air burst nuclear missiles**

(Density 100 men per 1,000 metre map square)

Yield KT	Casualties to men in open		Casualty saving per cent
	Unprotected	Thermally shielded	
1	310	220	29
10	2,050	460	78
100	13,500	3,000	78
1,000	85,000	18,500	78

It should be noted that with very low yield weapons the saving effected by protecting men from the heat effects is reduced and protection against the nuclear radiation becomes the dominant feature.

Mixed protection

386. In practice men will not all be in the same degree of protection at the instant of detonation. On any battlefield there will always be a certain number of persons whose duties necessitate their exposure in the open for at least a limited period. The remainder will be in varying degrees of protection according to the nature of their duties. Table XX(*d*) makes an estimate of the number of men who would become immediate casualties as the result of the bursting of a 10 KT missile at a medium height in the air over a defensive position of mixed protection. It is assumed that the men are dressed in steel helmets, wool battledress and that they are going about their daily business at the instant of burst. The density is assumed to be 100 men per 1,000 metre map square.

TABLE XX(*d*).—**Estimated immediate casualties in a defensive position of mixed protection**

(Density 100 men per 1,000 metre map square)

Form of protection	Proportion of men in that protection, per cent	Immediate casualites
In open—unprotected other than by clothing . .	10	205
In open—shielded against the heat	20	93
In open slit trenches	30	96
In slit trenches shielded against the heat . .	25	55
In trenches with 18 inches overhead protection . .	15	12
	100	461

A study of Table XX(*d*) shows that nearly half of the total casualties are from men in the open, unprotected from the heat effects, even though these formed only 10 per cent of the total force. Clearly there will be a

considerable saving in casualties if men can be kept under cover. Had only 5 per cent been exposed instead of 10 per cent, the total casualties would have been 359 instead of 461, a saving of 102 casualties, or 22 per cent.

Clothing

387. In all the foregoing examples it is clear that clothing has an important part to play in protecting the soldier from the heat effects and from beta burns from any residual radiations. Properly designed clothing and equipment must aim to cover up all exposed skin without interfering unduly with freedom of movement, bodily comfort and ease of handling weapons. Where proper clothing does not exist resource must be made to improvisation. The ordinary issue woollen glove gives good protection to the hands, whilst a cap comforter will give added protection to the face, ears and neck until such time as a satisfactory face mask or veil has been designed and issued. Two thicknesses of material (ie, battledress blouse and shirt) are better than one, three thicknesses better than two, particularly where an air space is formed between the material and the skin as with a string vest. Colour and material are also important, light colours offer better protection than dark; wool is a good material. Cotton is a bad material since it catches fire readily.

Differing aspects of protection

388. From the foregoing paragraphs it is clear that there are two different aspects of protection:—

(*a*) The individual's.

(*b*) The commander's.

The individual's natural instincts will be to put as much between himself and the burst as material and time will allow. The commander's aim will be to achieve the greatest protection for the maximum numbers with the minimum of effort and material. These two aspects will be dealt with separately.

Individual protection

389. The aim of the individual is to reduce his own chances of becoming a casualty and so increase his chances of survival. If there is sufficient warning of nuclear attack (which is not very likely), the obvious solution is to remain under cover or to make for the best shelter available as quickly as possible and stay there. In general, the action for self-preservation follows that for an attack by ordinary HE weapons. If duties necessitate being out in the open ensure that proper clothing is worn; in any case ensure that all exposed skin is covered up. If caught away from cover by a surprise nuclear attack take the immediate action drill as set out in paras 391 to 395.

390. In the event of a surprise attack by nuclear weapons there are certain actions a man can take which may mean the difference between life and death. In order to get these actions in their true perspective it would be as well to recapitulate some of the facts mentioned earlier in this pamphlet:—

First.—The intensely bright flash of light (which is the warning sign for the immediate action drill).

greatest damage when the target is a built-up area. The shelter is further provided with anti-blast walls which should cover about half the width of the shelter, to shield the entrances and exits. The principles of construction are illustrated diagrammatically at Fig 38. An example of the protection afforded by such a shelter against the immediate nuclear radiation is—At 700 yards from a 20 KT weapon burst at about 600 feet above the ground, the intensity of the immediate nuclear radiation would be about 10,000 roentgens. Since the radiations will be passing through the concrete at an angle and, therefore, through more than the base two feet of concrete, the dose rate inside the shelter will be about 150 roentgens.

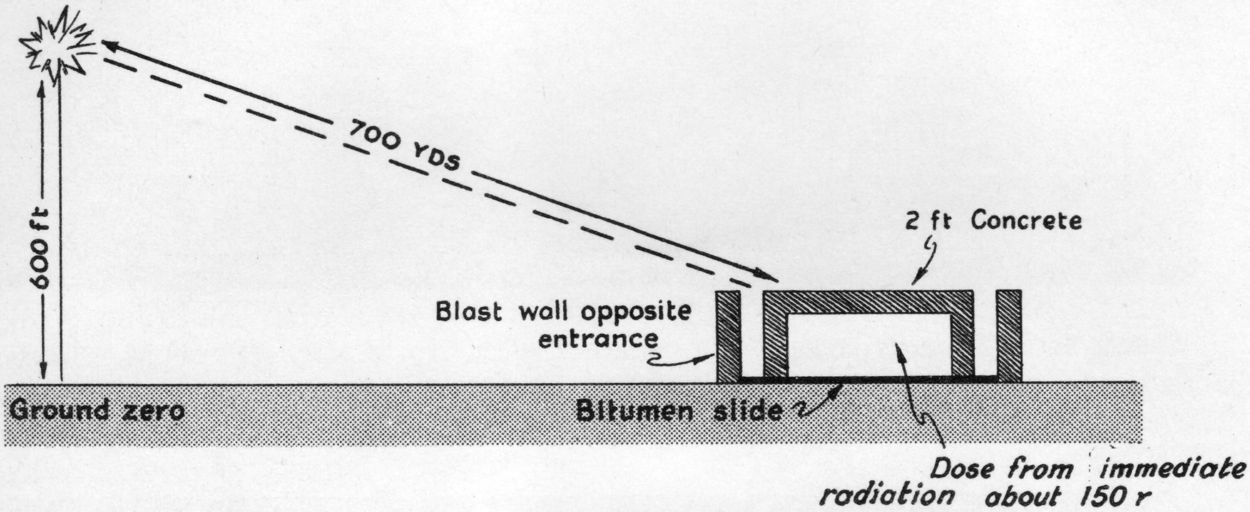


Fig 38.—Diagrammatic representation of a typical Civil Defence surface shelter in the United Kingdom

Protective measures in buildings

407. In the absence of specially constructed shelters, the safest place in stone or brick buildings is in the basement near the walls; the next best place is on the lowest floor of an interior room, passage or hall, away from windows and doors and, if possible, near a supporting column. An individual in such a position would be completely protected from heat and well protected from the direct effects of blast and from the immediate nuclear radiation. The chief danger would be from flying glass or other debris, from being crushed or trapped by falling beams or masonry or from being trapped, burnt or suffocated.

408. If there is any warning of nuclear attack, blinds and shades should be drawn to keep out heat radiation and help to shield the occupants from flying glass. Whitewash on windows, whilst permitting light to filter through, will greatly reduce the amount of heat penetrating through them.

409. Wooden buildings are very vulnerable to blast and fire and provide little or no shielding against the immediate nuclear radiation. If, however, an individual has no option it would be preferable to take shelter under a bed or table in such a building rather than to go out into the open.

410. Reserved.

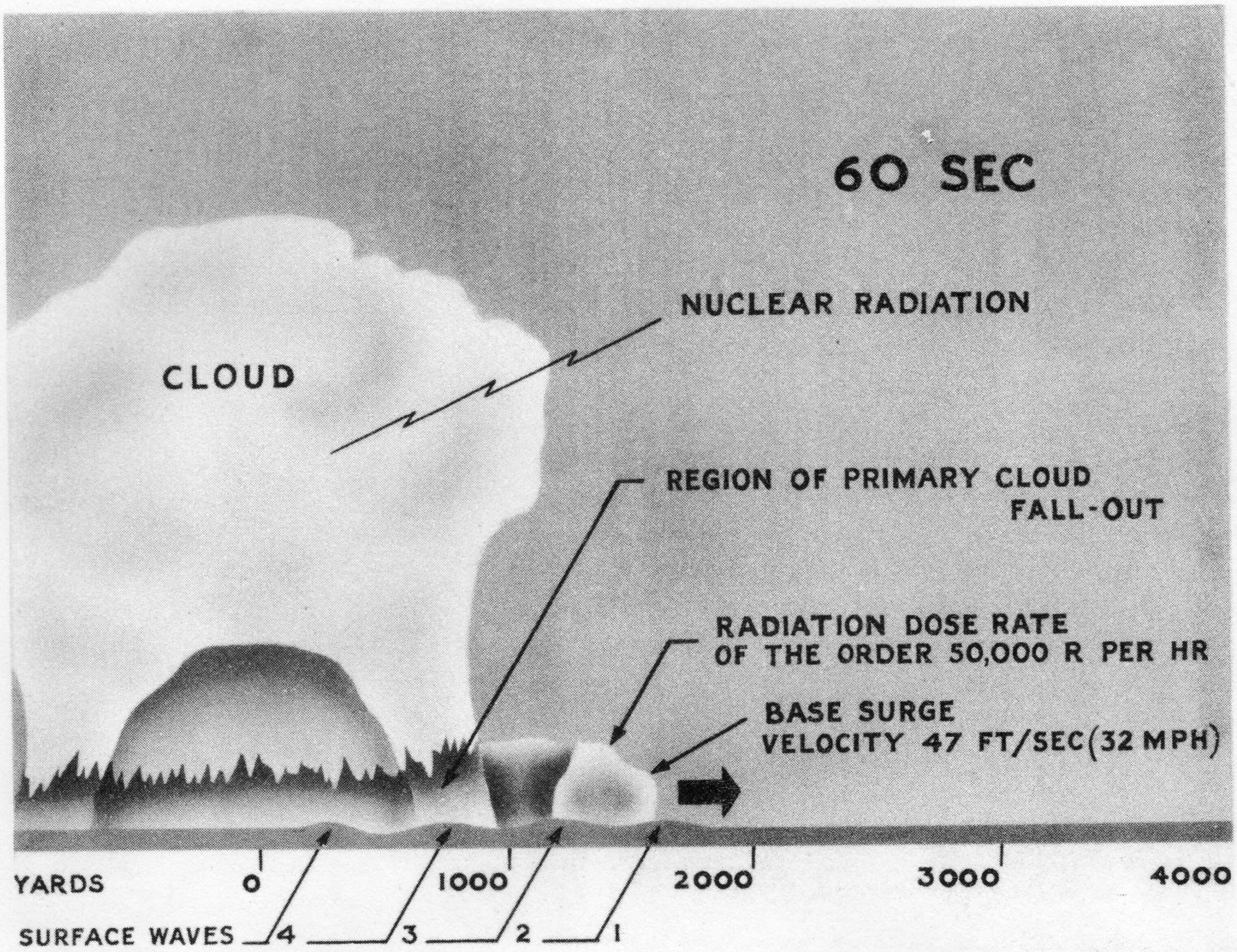


Fig 40(*d*).—Chronological development of an underwater burst : 60 seconds after detonation

Sixty seconds after the detonation the water from the cauliflower cloud reached the surface of the lagoon as indicated in the region of primary cloud fall out in Fig 40(*d*). There was thus an essentially continuous ring of water and spray between the surface of the water and the cloud.

At this time the base surge had become detached from the column so that its ring-like character was apparent, as shown in cross section in Fig 40(*d*). The height of the base surge was now about 1,000 feet and its front moving outwards at a speed of 47 feet per second (30 knots or 32 mph) was approximately 1,600 yards from the ground zero. Note the intense radioactivity indicated by the dose rate of the order of 50,000 roentgens per hour.

Several water waves had now developed ; the first with a height of 19 feet from crest to trough, being 1,600 yards from the ground zero.

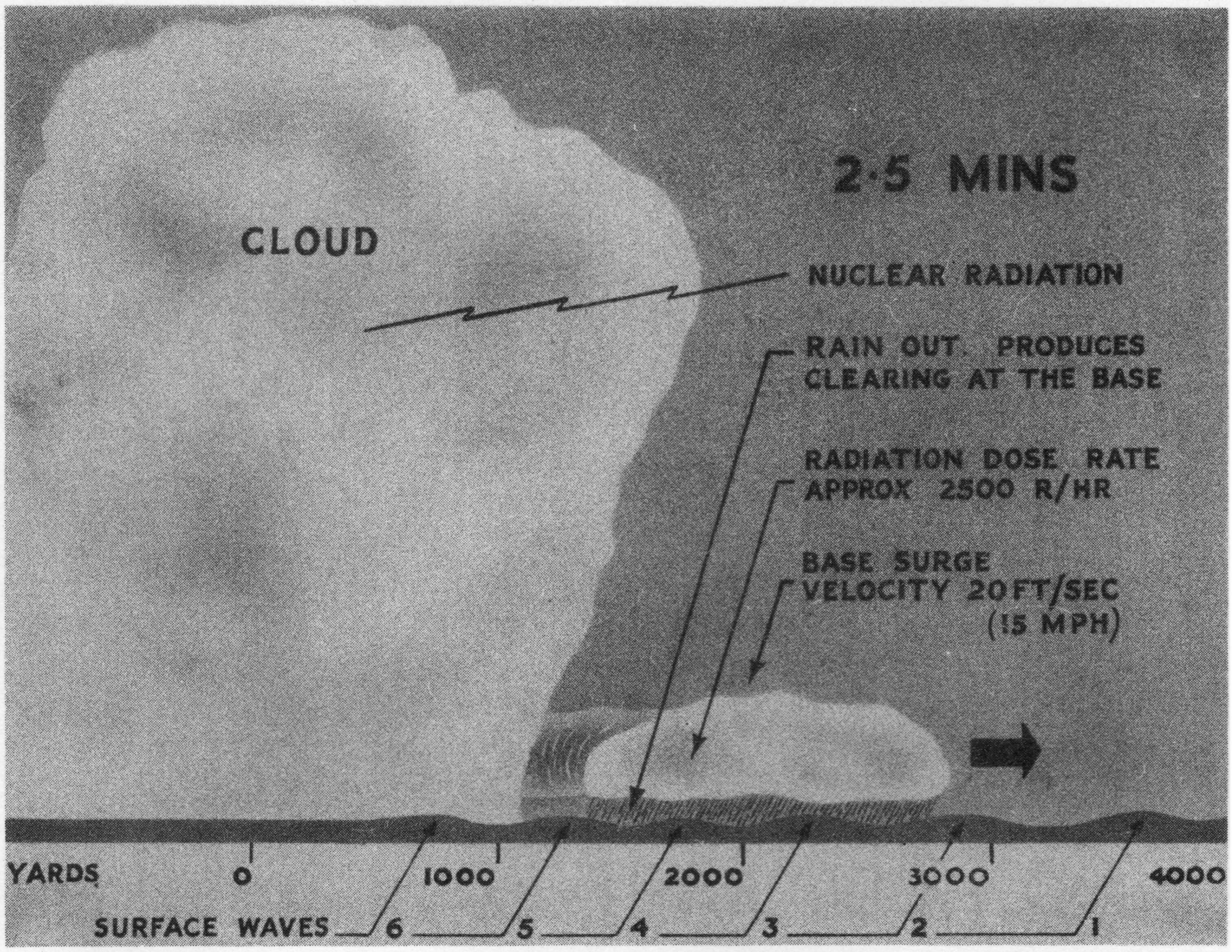


Fig 40(*e*).—Chronological development of an underwater burst: $2\frac{1}{2}$ minutes after detonation

Two and a half minutes after the detonation the front of the base surge was about 2,700 yards from the ground zero and had almost attained its maximum thickness of about 600 yards. The greatest effective spread of the base surge, reached in roughly 4 minutes was approximately 3,000 yards from the ground zero or nearly $3\frac{1}{2}$ miles across. Owing to natural decay of the fission products, to condensation of the water and thinning out of the mist by air, the nuclear radiation dose rate had decreased to 2,500 roentgens per hour. While this is much less than at 60 seconds (Fig 40(*d*)) it is still very considerable. At about this time the base surge appeared to be rising from the surface of the water. This effect was probably due to several causes, such as the actual increase in altitude, the thinning out of the cloud by engulfing air and raining out of the larger drops of water.

The descent of water and spray from the column and from condensation in the cauliflower cloud resulted in a continuous mass of cloud or mist down to the water surface. Ultimately this merged with the base surge, which had spread and thinned out, and with the natural clouds of the sky to be finally dispersed by the wind.

The first water wave was now about 4,000 yards from the ground zero and approximately nine feet high from crest to trough.

465—485. Reserved.

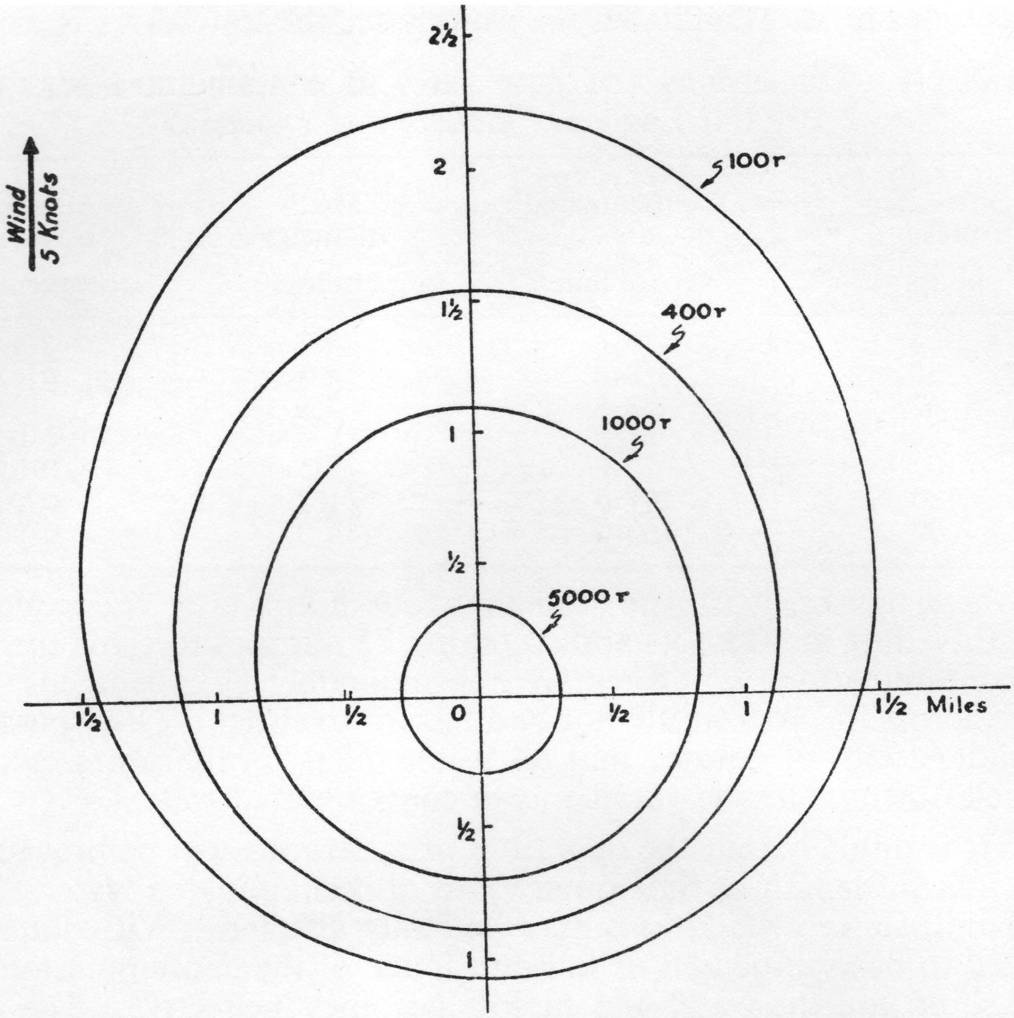


Fig 41.—Transit dose of radiation received from the base surge at various distances from the ground zero of an underwater nuclear explosion

It will be seen that a person exposed to the transit dose at a distance of 1½ miles would have received 450 roentgens, a fifty-fifty chance of life or death. This shows how vital it is to be fully under cover, with doors, windows, ventilators etc., closed during the first few minutes following an underwater burst. Radio-active rain may continue to fall from the base surge cloud for some time. Shelter from the rain, to prevent clothing from becoming contaminated, can be the only precaution to be taken immediately.

493. In an underwater burst most of the radio-active fission products will eventually fall back into the water. Since these substances will be spread through a large body of water, the hazard will not be serious except in the immediate vicinity of the ground zero shortly after the event. Because of the large amount of sodium present in sea water in the form of salt, it might be thought that neutron induced activity would add to the contamination of the water. This does not happen since most of the neutrons produced in the fission process are absorbed by the hydrogen in the water, to form the non-radio-active product deuterium or heavy water. Some radio-active sodium will be formed but the quantity will be small and, with a half-life of only 15 hours, will soon lose its activity.

494. Due to the presence of sodium and to the rapid settling of the fission products the sea water loses its radio-activity rather more quickly than fission products on land. The rate of decay follows the $t^{-1 \cdot 3}$ law. Tests taken at BIKINI show that the fission products were distributed over an area of some 60 square miles. Later tests showed, that once settled on the bottom, there was no tendency for the contaminated material to spread.

Table XXII gives the area, mean diameter and observed dose rates at various times for contaminated sea water after the test BAKER explosion.

TABLE XXII.—**Dimensions and dose rates of contaminated sea water at BIKINI Lagoon. Underwater explosion**

Time after explosion hours	Contaminated area square miles	Mean diameter miles	Maximum dose rates roentgens/hour
4	16·6	4·6	3·1
38	18·4	4·8	0·42
62	48·6	7·9	0·21
86	61·8	8·9	0·042
100	70·6	9·5	0·025
130	107·0	11·7	0·008
200	160·0	14·3	0·0004

From these figures, it can be seen that four hours after the explosion, a vessel, travelling at 10 knots and so taking 25 minutes to cross the area of gross contamination, would receive approximately 1·3 roentgens, so that passage across the area would not be a hazard to either crew or passengers. It is understood, of course, that all water inlets, evaporators etc, would be closed down while the vessel was in contaminated waters.

495. It is unlikely that the operation of a harbour will be prevented for any significant length of time on account of contaminated water. On the other hand, shore installations may be badly affected. With ships afloat subjected to base surge and/or fall-out, much of the contamination drains off the ships into the water and rapidly becomes ineffective. The process can be hastened and contamination of ships further reduced by a system of pre-wetting.

Summary of the residual hazards from various types of burst

496. A summary of the residual hazards to be expected from the various types of nuclear explosion is given briefly in Table XXII (*a*).

TABLE XXII (*a*).—**Residual hazards from nuclear explosions**

Type of burst	Hazard	
	Induced radiation	Fall-out
High or Medium air burst		
above 10 KT	None	None
below 10 KT	None	None, but rain out possible
Low air burst	Some around GZ	None
Surface burst	Some, but fission products predominate	Considerable
Shallow underground burst	Some, but fission products predominate	Considerable and possibly dust cloud
Deep underground burst ..	Some, but fission products predominate	Depends on whether burst vents or not
Shallow underwater burst	None	Considerable. May be accompanied by highly radio-active base surge
Deep underwater burst ..	None	Depends on whether burst vents or not

499. It must be realized that intensities (dose rates) and dose rate contours do not, by themselves, give an indication of the hazard of the likely casualty rate. It is the *total dose* that matters. A casualty-producing total dose may be acquired by remaining in a field of

(*a*) low intensity for a long time

(*b*) high intensity for a short time.

This is illustrated in Table XXIII (*a*) below, which is an adaptation of the " 7 and 10 " rule given in Table XXIII above.

TABLE XXIII (*a*).—**Total dose in relation to the decay law**

Time t	Dose rate at Time t	Total dose absorbed, r								
		(*a*) From time t to infinity (*b*) *Between the times shown*								
		Unprotected			Slit trench (protection factor of 10)			Cellar with protection factor of 100		
	r/hr	(*a*)	(*b*)	(*c*)	(*a*)	(*b*)	(*c*)	(*a*)	(*b*)	(*c*)
H + 1 hr	1,000	5,000			500			50		
			1,500			**150**			**15**	
H + 7 hrs	100	3,500		**2,500**	350		**250**	35		**25**
			1,000			**100**			**10**	
H + 49 hrs (2 days)	10	2,500			250			25		
			750			**75**			**7·5**	
H + 14 days (2 weeks)	1	1,750		**1,250**	175		**125**	17·5		**12·5**
			500			**50**			**5**	
H + 14 weeks (3 months)	0·1	1,250			125			12·5		

500. The following " rules of thumb " based on the " 7 and 10 " law, may be found useful for quick approximations:—

(*a*) *Doubling the time halves the dose rate*

Example. If at H + 12 the dose rate is 50 r then at H + 24 it will be 25 r: at H + 48 it will be 12 r and so on.

(*b*) *Dose to infinity.* D = FIT where D= dose, F = 5 (five), I = Dose rate (or intensity) at a time T, T = time of entry into the contaminated area, measured from the time after detonation. This rule requires a knowledge of the time of burst.

Example. A person enters a contaminated area two hours after detonation. The dose rate at the time of entry is 7 r/hr. What is the approximate total dose he would receive if he remained in the area permanently without protection?

Solution. $D = 5 \times 7 \times 2 = 70$ r.

Radiological warfare agents

501. Radio-active material, apart from the nuclear weapon, could be used directly for military purposes with the object of contaminating personnel, equipment, structures or areas to such an extent as to cause

casualties or to cause evacuation of an important area such as a city, an industrial area, a military establishment or an airfield without actually destroying it. In course of time the activity of the contaminating material would decay and the area could be reoccupied with little or no rehabilitation. Such a use of radio-active material is referred to as *radiological warfare*, abbreviated to RW, and the contaminating material is called the RW agent.

502. There are four types of nuclear radiation which are harmful to the human body namely neutrons, alpha praticles, beta particles and gamma rays. Since the only practical method of delivering and dispersing neutrons appears to be the nuclear weapon, neutrons are not considered as RW agents. Alpha emitters are of little value as RW agents since they can do no harm unless they enter the body. On the other hand, radio-active materials emitting beta particles and gamma rays offer possibilities for use as RW agents.

503. The main requirements for an RW agent are:—

(*a*) It should be a gamma emitter.

(*b*) The energy of the radiation must be fairly high so that its penetrative powers will be reasonable.

(*c*) Its half-life must be neither too long nor too short. A reasonable bracket is between two weeks and six months. If the half-life is very short its decay rate will be so rapid that it will have to be manufactured immediately before use, hence stockpiling will not be feasible. On the other hand radio-active substances with long half-lives have relatively weak activity and so would have to be used in large quantity to be effective. Furthermore, such substances may deny subsequent reoccupation of the area.

504. Apart from the nuclear weapon (which can be an indirect RW weapon), RW agents may be produced in two ways, both of which involve the use of a nuclear reactor or pile. The first method is to use the radio-active fission products which are a by-product of nuclear reactors. The complex mixture so obtained could be used directly as an RW agent. Its chief disadvantage is that it consists of so many substances of various half-lives that, whereas the initial activity falls off rapidly, some activity will linger for years. This disadvantage might by overcome by extracting a particular radio-active isotope, having desirable RW properties, from the mixture but the extraction process would be difficult and costly. The mixture is so complex that no single element represents more than about three per cent of the whole. The second method is to expose selected non-radio-active elements to the action of neutrons in a reactor. By proper choice of materials RW agents of the required characteristics could be prepared. The construction of reactors for the sole purpose of producing RW agents would be costly and economically unsound.

505. RW agents differ from other weapons, including nuclear weapons, in two important respects. Firstly, all other weapons can be made in advance in preparation for an emergency and can be stored for a long time without risk of serious deterioration. This is not so with RW agents. Stockpiling is virtually impossible because natural decay will result in a continuous loss of active material. The production of RW agents is a slow process and the continual and unavoidable loss represents a serious drawback. Secondly, all other weapons can be handled with comparative safety. An RW agent, because it will be emitting gamma rays of considerable penetrating power, will require a complicated procedure for

510. As explained in Section 8, when a nuclear weapon is detonated many neutrons are released and are ultimately captured by the weapon material, by the nitrogen (especially) and oxygen in the air and by some of the elements contained in the earth's surface. As a result of neutron capture many of these substances become radio-active, emitting beta particles, frequently accompanied by gamma radiation of high energy, over an extended period of time. Such neutron induced radio-activity is part of the residual radiation. It is known as *induced radiation* and is present following low air, surface and sub-surface bursts. It has no tactical significance under the latter two circumstances because the residual radiation from the fission products is so vast and covers such a large area that induced activity can be ignored by comparison.

511. From the low air burst, however, many of the neutrons released in the fission process strike the ground in the vicinity of the ground zero, penetrating to a depth of about 18 inches and inducing radio-activity into some elements such as aluminium, manganese, iron, potassium and sodium. Relatively small amounts of these elements, when irradiated, produce gamma radiation of high intensity which can be a hazard to troops operating in the area. The pattern is a roughly circular area around the ground zero. It is unaffected by weather or winds except, perhaps, for some displacement of top soil. Because of the depth to which the induced activity may extend decontamination is difficult. Most of the radio-activity is contained in the top four inches of soil; if this is removed the nuclear radiation will be considerably reduced. The area may also be sealed by covering with earth, but this only reduces the radiation and does not remove it.

Decay rate

512. The decay rate of induced radiation differs fundamentally from that of the fission products (fall-out) which follows the $t^{-1 \cdot 2}$ law generally. The type, intensity and energy distribution of neutron induced activity will depend on the variety and quantity of the isotypes produced. This, in turn, depends on the number and energy distribution of the incident neutrons and on the chemical composition of the soil. The elements which contribute most of the activity are certain isotopes of aluminium, manganese and sodium. Other substances either emit so little nuclear radiation or decay so rapidly that they are less important. Almost all soils contain aluminium; most soils contain manganese, which is an essential to plant life, and sodium. The isotopes formed are:—

Aluminium 28 ($_{28}$Al, half-life 2·3 minutes).—Although contributing greatly to the high initial activity, it decays quickly and very little remains after the first hour following a nuclear explosion.

Manganese 56 ($_{56}$Mn, half-life 2·6 hours). The most important contributor for the next few hours.

Sodium 24 ($_{24}$Na, half-life 15 hours).—In the absence of manganese, the sodium content of the soil will probably determine the activity for the period and is the most important contributor following the decay of manganese.

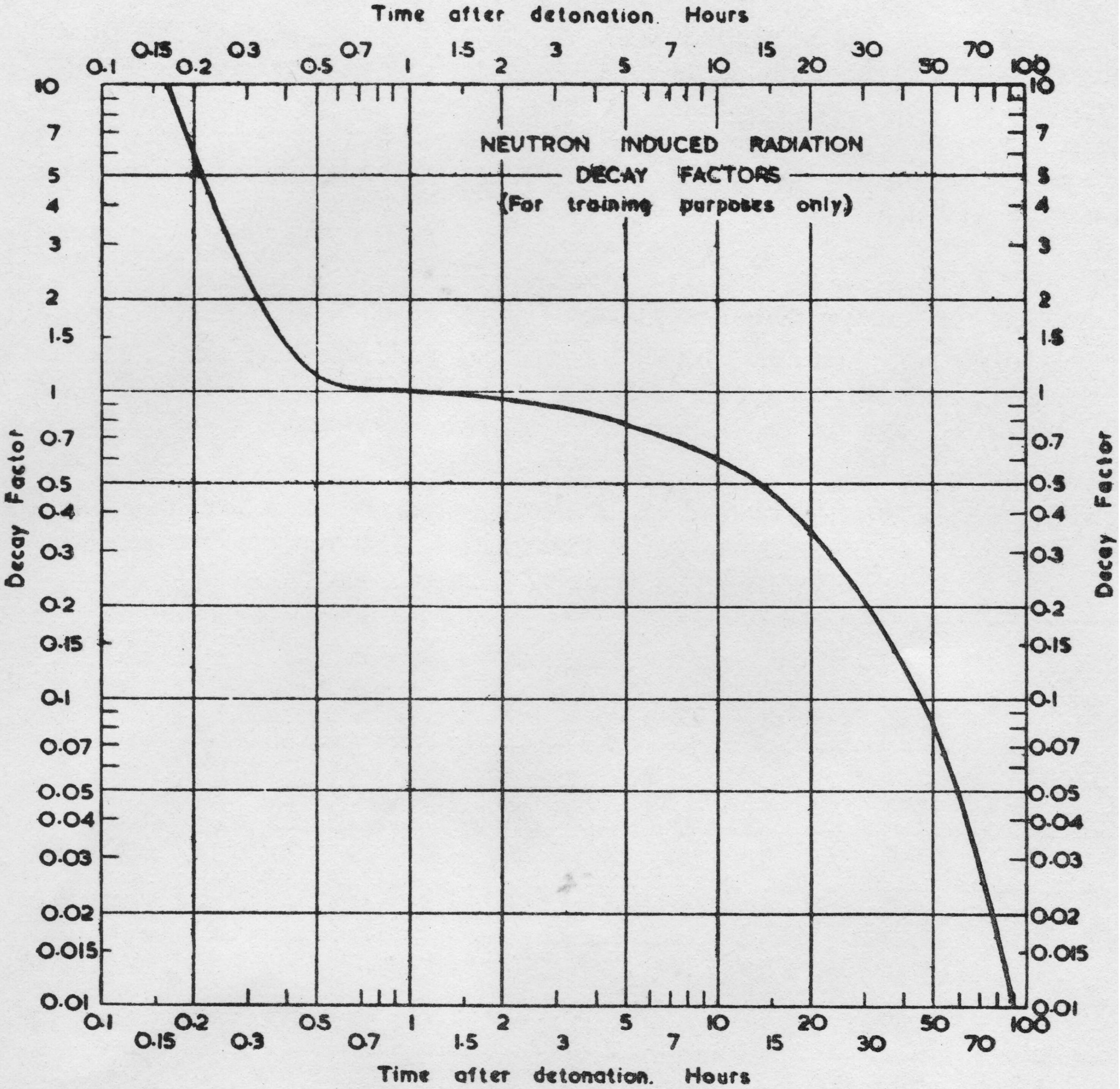


Fig 42.—Induced radiation decay factors (for training purposes only)

Operational significance of induced radiation

515. Induced radiation from low air bursts can have an important effect on the battlefield by limiting movement on foot in, and the physical occupation of, the areas affected. However, any part of the area can be crossed safely by AFVs and, to a lesser extent, by vehicles which provide some protection against residual radiation (*see* Table XLIV (*a*)) of which induced radiation is a part.

516. In general, the area of induced radiation should be avoided. It is quite easily recognized by the roughly circular shape of scorched, blackened and windswept vegetation and ground. The exact area to be avoided depends on the weapon yield, the height of burst, the nature of the soil etc. It may be taken that with tactical weapons the hazard does not exist beyond 1,000 yards from the centre of the devastated area.

517. If the area must be crossed, it should be crossed quickly and, if possible, in vehicles, armoured vehicles being used for preference. An ordinary, unarmoured vehicle has a protection factor of between two and three against residual contamination on the ground so that the dose received by the occupants will be reduced to about one half or one third. Covering the floor of the vehicle with filled sandbags will reduce this dose by a further fifty per cent. Before attempting to cross the area it should

be reasonably certain that troops will not be stopped and held in the area by obstacles or enemy action since by far the greatest advantage to be gained by the use of vehicles is in the rapidity of the crossing. Table XXIII (*d*) illustrates the total dose that might be received by personnel on foot, in 3-ton trucks, APCs and medium tanks using either of two parallel routes to cross neutron induced radio-active ground at H + 1 hour, following a 20 KT low air burst nuclear missile. Route AB passes through the ground zero. Route XY is offset about 500 yards.

TABLE XXIII (*d*).—**Crossing an area of induced radiation**

Method of crossing	Total dose in roentgens	
	Route AB through the GZ	Route XY offset 500 yards
On foot	125	70
3-ton truck	10	7
APCs	4	3
Medium tanks	1	1

The average intensity along a route through the ground zero is usually about one third of the highest intensity encountered. No allowance for decay need be made because crossing times are so short that any decay taking place is insignificant.

518. It may happen that an objective previously attacked by a nuclear weapon has to be taken and held. The commander faced with such a problem must locate and accept the pattern of induced radiation and organize his defences around the contaminated area, remembering that the pattern shrinks with the passage of time and in about a week is of negligible size.

519–524. Reserved.

SECTION 18.—FALL-OUT

Introduction

525. Fall-out is the name given to the weapon residues, dust and debris which fall back to earth from the nuclear cloud. Although fall-out from a true air burst has no military significance, a study of what happens inside the fireball gives the basic reasons why fall-out could be a hazard from other types of explosion.

An air burst

526. Immediately following a nuclear explosion the air around the burst is heated until it attains extremely high temperatures and pressures and appears as a roughly spherical luminous mass known as the fireball. Inside the fireball are the following radio-active materials:—

(*a*) Vaporized remains of the weapon casing which probably have had radio-activity induced in them as the result of capture of neutrons released in the explosion.

(*b*) Unfissioned weapon material, in itself radio-active.

(*c*) The products of the fission process, which are the principal source of radio-active materials. (There are no radio-active products from the fusion process.)

The hot mass of gas rises as it cools and a strong turbulence sets in causing a rapid mixing of everything inside. This usually takes place in the form of a toroid or smoke ring, the gases moving upwards in the central vent and circulating over the top and down the outside of the ring and so up the centre again to repeat the process. As the fireball cools some of the vapours condense to form a visible rising cloud which appears to an observer as a gigantic growing mushroom, inside which the toroidal mixing is taking place.

527. With a true air burst (ie, where the fireball does not touch the ground) the up-draught caused by the rapidly rising mushroom cloud may be sufficient to draw upwards a stream of dust and debris from the ground. This stream rises upwards towards the centre of the toroid or smoke ring of the main cloud and appears, to an observer on the ground, to join the main cloud and so form the stem of the mushroom. In fact, the stream of dust particles and debris pass through the centre of the toroid and curl round down the outside but do not mix with the main cloud. Any radio-activity originally induced in the dust and debris of this stream by neutrons released by the explosion is not significantly increased nor do the particles act as centres on which the unfissioned or vaporized weapon materials or the fission products condense. When this dust and debris subsequently falls out, due to the pull of gravity, there is relatively little residual radio-activity from it. The original weapon material and fission products in the toroid which have already condensed into much smaller particles, will rise much higher, take longer to fall, be much more widely spread and decay more before reaching the ground, so that they too, cause little residual radio-activity. Evidence from NAGASAKI shows that there was an area of fall-out about one and a half miles east of the ground zero which registered an intensity of 800 microroentgens per hour 96 days after the explosion. The calculated dose rate at one hour after the explosion works out at 8·7 roentgens per hour. There were other traces of fall-out as far as 30 miles downwind of the ground zero but this did not constitute a hazard. No casualties were attributed to fall-out from the nuclear explosion at HIROSHIMA.

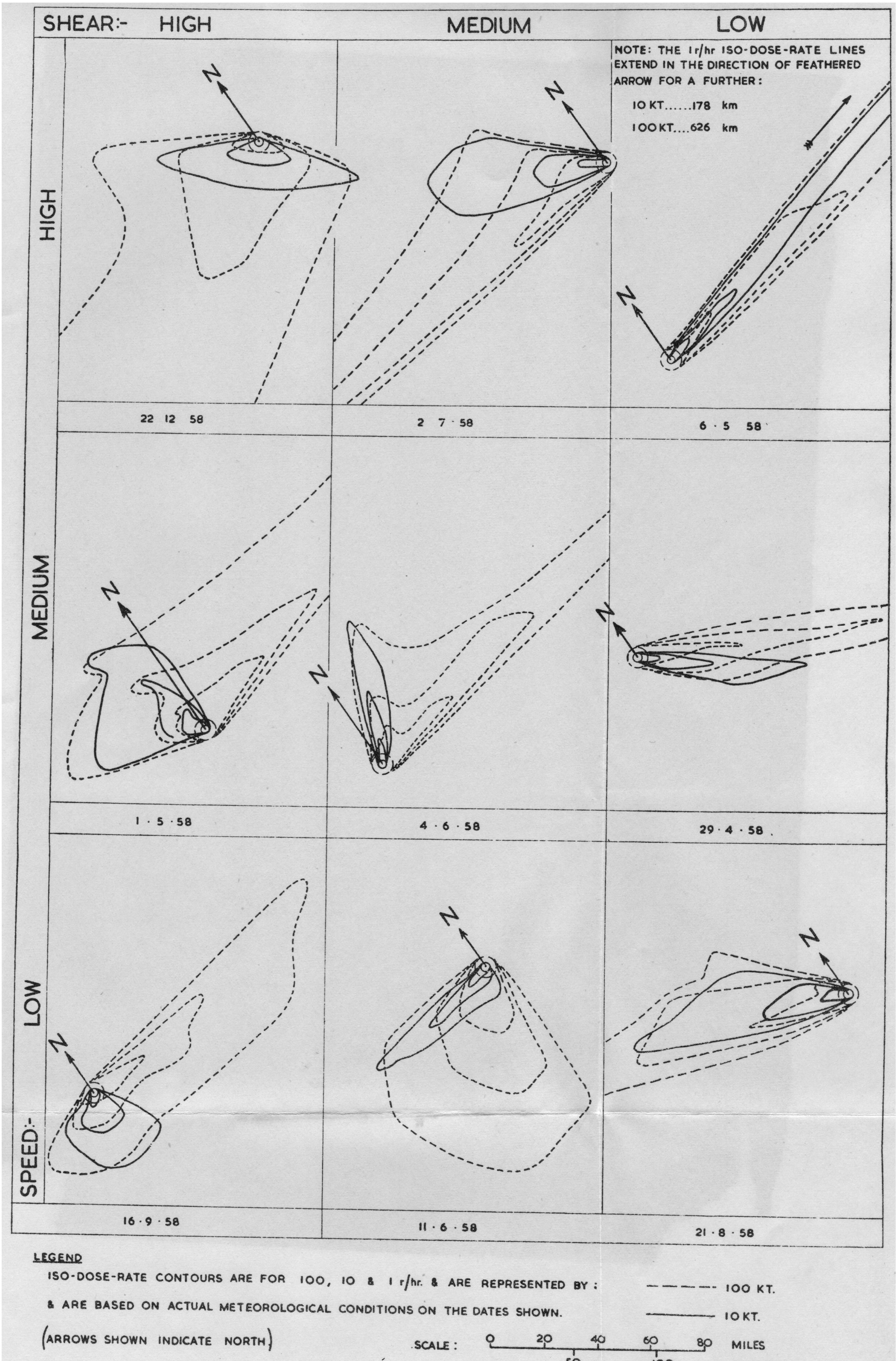


Fig 45(a) Salisbury Plain fallout predictions

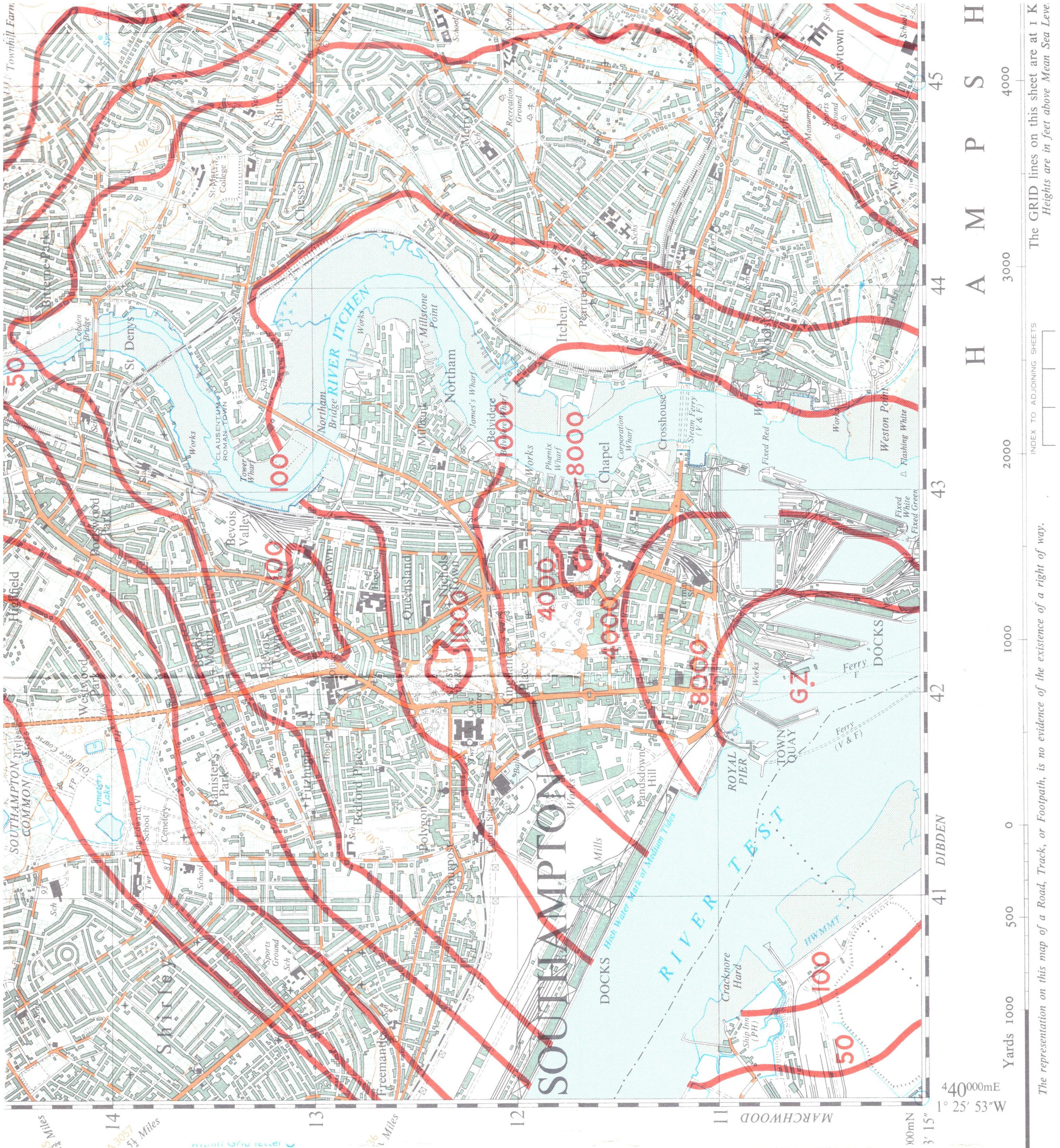
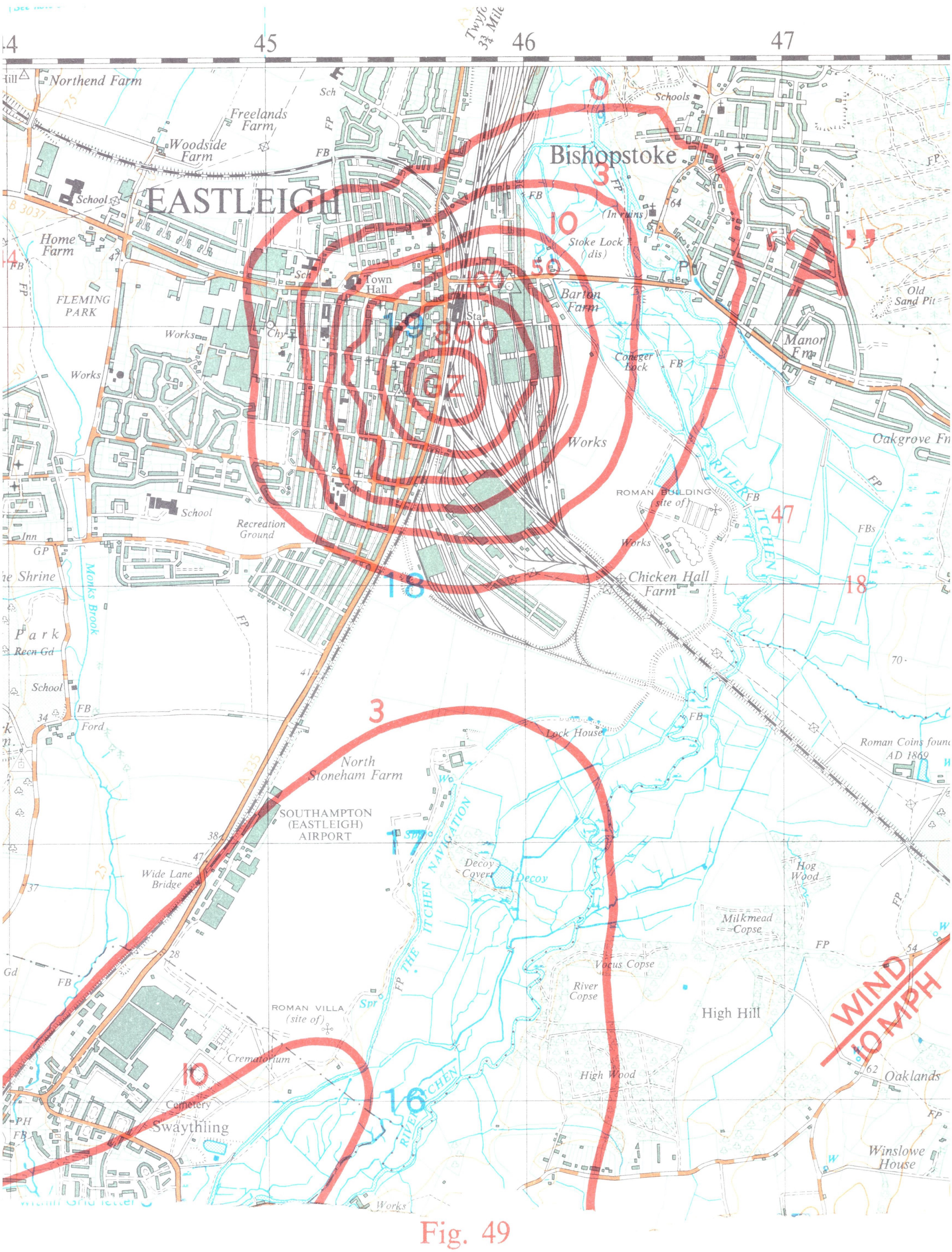


Fig. 49

An overlay showing isodose lines as they might be plotted at a control centre from monitoring data corrected to one hour after detonation. At "A" an air burst nominal nuclear weapon has been assumed. At "B" a nominal nuclear weapon burst underwater in a shallow harbour has been assumed. Wind 10 miles per hour in both cases.



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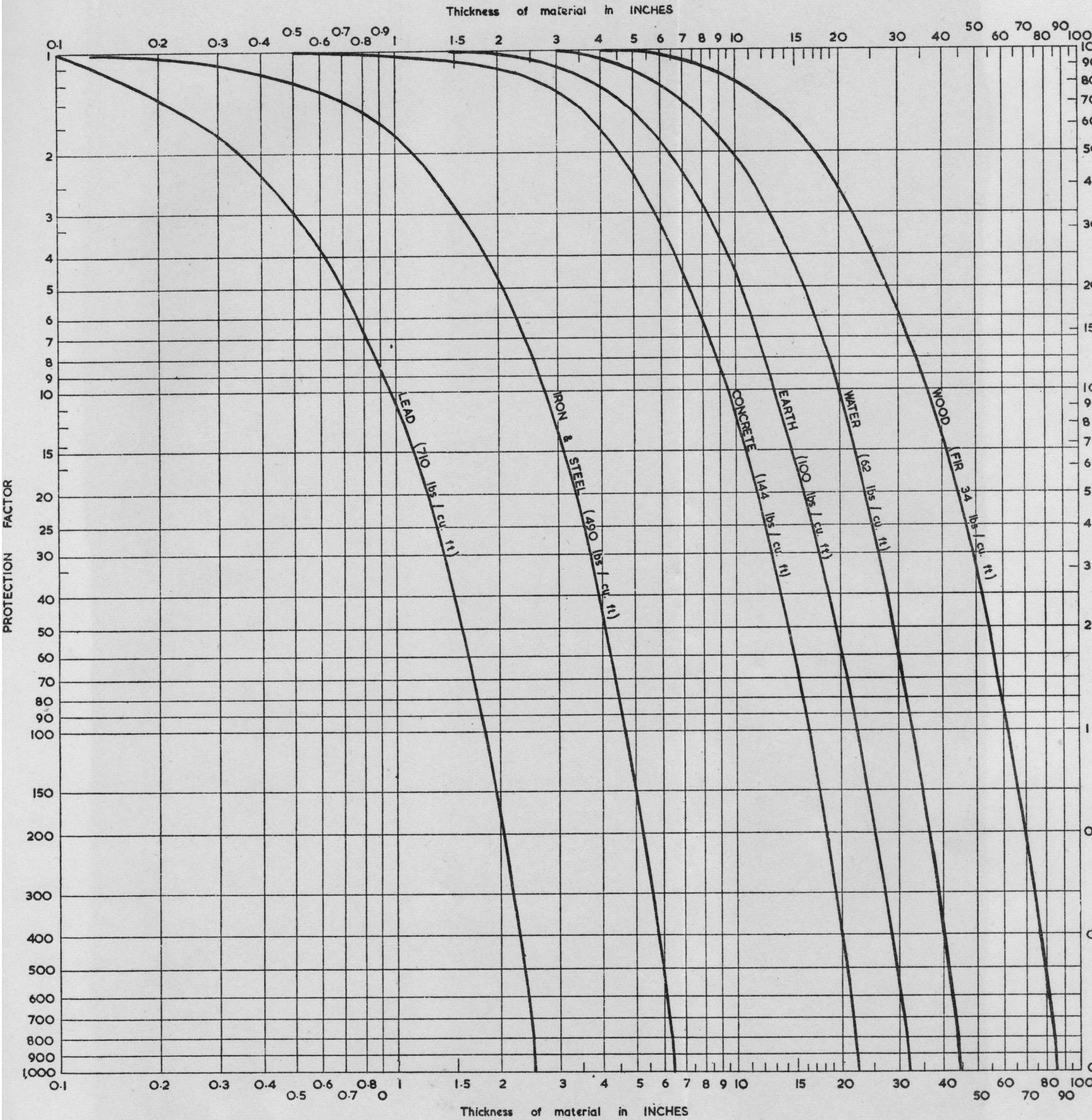

Fig 48 (*b*).—The attenuation of the residual gamma radiation from the fission products (0·7 MeV) *to face 148J*

TABLE XXXVI (*b*).—**Acute effects of beta radiation on the skin**

Total dose (rads in skin) (if absorbed in up to 1 week)	Effect
0 to 600	No acute effects
600 to 2,000	Moderate skin reddening
2,000 to 4,000	Moderate skin reddening within 24 hours, skin sores in 1 to 2 weeks
4,000 to 10,000	Severe skin reddening within 24 hours, severe skin sores in 1 to 2 weeks
10,000 to 30,000	Severe skin reddening within 4 hours, severe sores in 1 to to 2 weeks
30,000 to 100,000	Skin blisters within 1 day

The aim

928. The aim of fire prevention is therefore twofold:—

(*a*) To reduce the chances of an outbreak of fire to a minimum.

(*b*) Once a fire has started, to put it out as soon as possible.

Prevention measures

929. In general, preventive measures against the fire risk are a question of common sense and promptness in dealing with initial outbreaks. The following very simple precautions will greatly reduce the risk of an outbreak:—

(*a*) Keep surrounds clean and clear of trash and likely kindling fuels such as dried grasses growing round wooden buildings.

(*b*) Reduce to a minimum the amounts of combustible fuels kept in any one place.

(*c*) Reduce the inflammability of combustible materials by simple treatments such as covering sacks with tarpaulins, paint woodwork, fireproof curtains.

(*d*) Consider the effect of blast on the siting of heating and lighting appliances, electric circuits etc.

(*e*) Extinguish or contain initial outbursts before they become serious.

930. The everyday precautions against fires from ordinary causes are also most effective against the fire risk from nuclear attack but in face of a nuclear threat the following additional precautions are desirable:—

(*a*) *Buildings*

(*i*) Block up all unnecessary windows, skylights, etc having a direct view of the sky. Whitewash remainder, this simple procedure reflects about 80 per cent of the radiated heat without interfering greatly with the amount of light transmitted.

(*ii*) Shield openings not fitted with doors or shutters with sandbag walling or other incombustible screening.

(*iii*) Remove inflammable material from lofts and attics and from spaces directly opposite windows.

(*iv*) Remove curtains from windows or flame proof by soaking in a flame retardant solution.*

(*v*) Fit guards to open fire places to prevent contents being blown into room.

(*vi*) Non-essential gas, oil and electrical appliances should be turned off at the mains.

(*vii*) Fill baths with water and place buckets of water and sand in each room for speedy extinguishing of initial fires in fabrics etc before they develop. A stirrup pump is a useful addition, if procurable.

(*viii*) Cover flat roofs with a layer of sand or earth to a depth of at least 1 inch.

(*ix*) Whitewash exterior combustible untreated surfaces.

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* Suitable solutions are—3 lb boric acid + 2 lb sodium phosphate (or alternatively 3 lb borax + 2 lb boric acid) dissolved in 3½ gallons of water. Thoroughly soak fabric in solution, squeeze out excess moisture, rinse and dry.

(*b*) *Installations, Depots etc*

(*i*) Inflammable liquids such as petrol, oil and lubricants should be stored below ground and covered with a layer of earth. Storage sites should be well away from buildings and other stores and dispersed.

(*ii*) Firebreaks should be maintained between various stacks and storage spaces.

(*iii*) Easily ignitable materials, should be stored in trenches and covered with a layer of earth if possible, failing this store in buildings, or stack and cover with tarpaulins, the heavier the better.

(*c*) Forest and Heathlands. Maintain and keep firebreaks clear of woods and long grasses. Firebreaks must be at least 100 feet wide to be effective.

Firefighting measures

931. In the early stages most individual primary and secondary fires will be quite small and can be effectively dealt with by prompt and aggressive action, by the person on the spot. In many cases beating or stamping out will be all that is required. In more serious outbreaks the use of simple appliances such as buckets, fire extinguishers and stirrup pumps will be sufficient to prevent the outbreak spreading.

932. Once fires have taken hold a quick reconnaissance and appreciation will have to be made to determine the priority of the firefighting tasks and the deployment of the available manpower and firefighting appliances.

933. Because speed is vital it is essential that all ranks of all arms are trained to deal sensibly and quickly with outbreaks of fire and to use simple firefighting appliances.

934. Firefighting units will need to be:—

(*a*) highly mobile

(*b*) operationally flexible and self-supporting with adequate communications

(*c*) capable of overcoming the physical obstacles arising from nuclear attack

(*d*) organized and trained to make the fullest use of emergency water supplies—even though this may entail large scale relaying operations.

Dangers of fall-out

935. The smoke from fires in regions of dangerous levels of fall-out or induced radiation may present an internal radiological hazard. Personnel engaged in firefighting under these conditions will wear respirators and avoid working in the smoke (by keeping upwind) where possible.

936–940. Reserved.

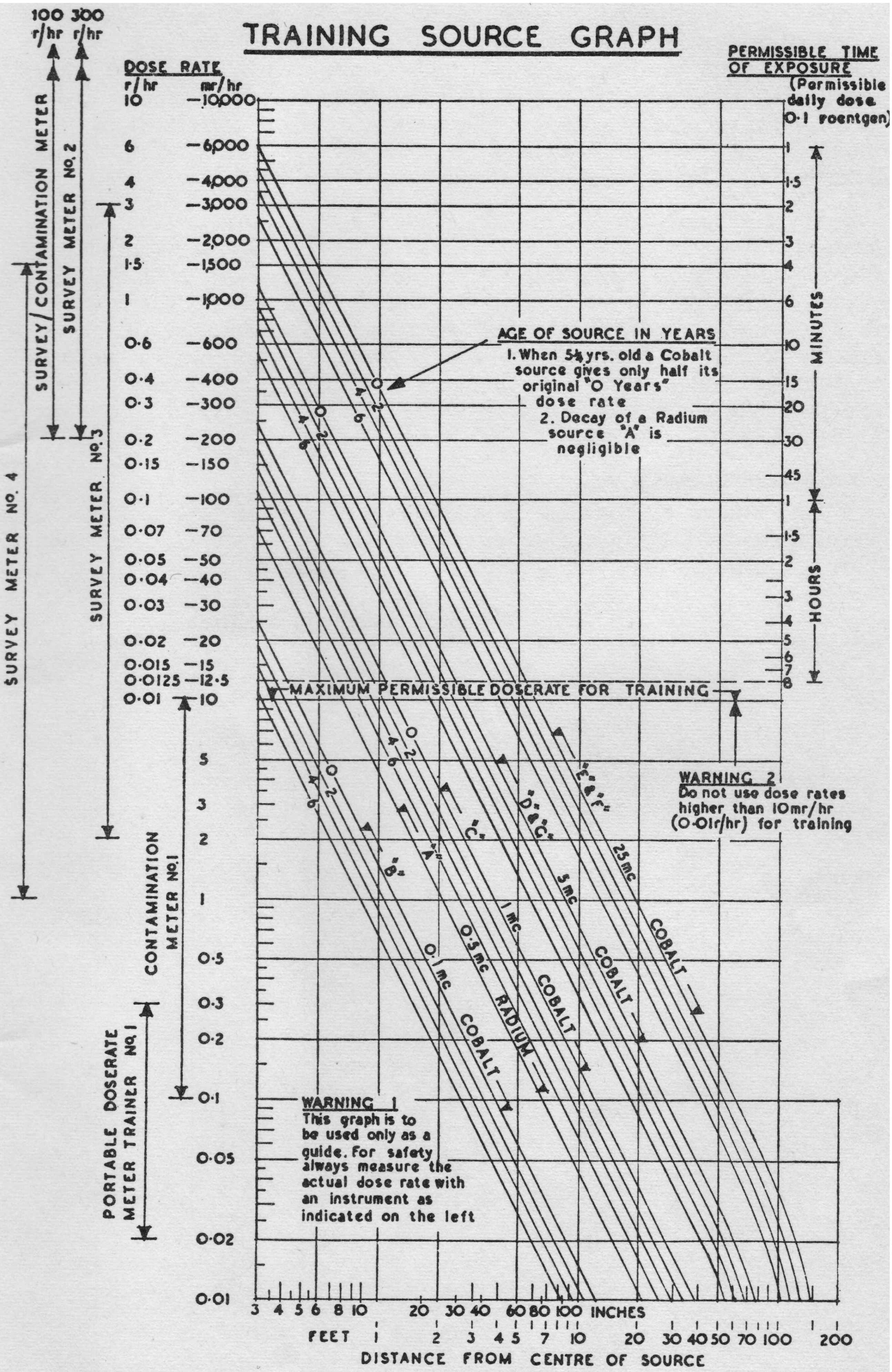

Fig 52A. Variation of dose rate with distance for training sources

TABLE XLIV (*a*).—**Nuclear radiation attenuation factors**

(INSIDE dose expressed as a proportion of the OUTSIDE dose)

Type of shelter	IMMEDIATE		Residual Radiation
	Neutrons	Gamma	
Tanks			
Light	0·7	0·3	0·2
Medium or heavy	0·5	0·2	0·05
Artillery S.P.	0·9	0·5	0·1
APC	0·8	0·6	0·25
Trucks			
¼ ton..	1·0	1·0	0·8
¾ ton..	1·0	1·0	0·7
3 ton..	1·0	1·0	0·6
Slit trench, open	0·3	0·1	0·1
with 1 foot earth overhead ..			0·001
with 2 to 3 feet earth overhead ..			0·005 to 0·003
Shelter, partly above ground			
with 2 feet earth cover	0·02	0·03	0·02 to 0·005
with 3 feet earth cover	0·01	0·04	0·005 to 0·001
Nissen hut	1·0	1·0	0·5
One storey brick house			0·1 to 0·05
basement	0·7	0·4	0·1 to 0·05
Multi-storey building			
upper floors..	1·0	0·7	0·01
lower floors	0·7	0·4	0·1
basement (surrounded by earth) ..	0·5	0·3	0·001
Built-up area, in open	1·0	0·5	0·8
Woods	1·0	1·0	0·8

For residual radiation, the addition of a layer of sandbags will introduce an additional attentuation factor of 0·5. Attenuation factors multiply together when two or more of the above are applied concurrently. For example the attenuation factor for a 3-ton truck with a layer of sandbags on the floor is $0{\cdot}6 \times 0{\cdot}5 = 0{\cdot}3$.